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THESIS

THE DEVELOPMENT OF A NAVAL BATTLE MODEL
AND ITS VALIDATION USING
HISTORICAL DATA

by

Thomas Reagan Beall

March, 1990

Thesis Advisor: Wayne P. Hughes, Jr.

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THE DEVELOPMENT OF A NAVAL BATTLE MODEL AND ITS VALIDATION USING HISTORICAL DATA

by

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ABSTRACT

This thesis describes the development and validation of a naval battle model which incorporates a tactical theory by Captain Wayne P. Hughes, Jr. Opposing forces are portrayed as aggregations of the staying power and combat power of their individual platforms. Attrition is modeled as a force-on-force process and is expressed in terms of the degradation of each force's combat power and staying power throughout the engagement. User variation of model inputs concerning the timing, direction and strength of each force's fire permits analysis of the impact of scouting effectiveness and C^2 on battle dynamics.

Data from fourteen historical naval battles were gathered to compute model input parameters for the opposing forces and their interactions. The model's prediction of the outcome is compared with each battle's actual outcome. The conclusion drawn from this analysis is that the model is a fair representation of reality.

The model's potential for practical application is explored by using it to analyze the tactical options of the U.S. commander at the World War II Battle of Savo Island. Model results clearly indicate the weaknesses in U.S. tactics in this battle and suggest alternative tactics which afforded a better chance of success.

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I. INTRODUCTION

A naval battle model's purpose is to assist the tactical planner in thinking about how best to employ his forces to win a battle. To be useful, such a model must be able to handle complex scenarios, be simple to implement and use, and produce credible results. It must also be built upon assumptions grounded in sound tactical theory.

Captain Wayne P. Hughes, Jr. has developed the theory upon which a model can be built. He has summarized it in four simple statements [Ref. 1]:

- Naval warfare is attrition centered. Attrition comes from successful delivery of firepower.
- Scouting is a crucial and integral part of the tactical process.
- Command and control transform firepower and scouting potential into delivered force upon the enemy.
- Naval combat is a force-on-force process involving, in the threat or realization, the simultaneous attrition of both sides. To achieve tactical victory, one must attack effectively first.

While Hughes' theory has received wide acceptance, there has never been an attempt to translate it into a model which can assist naval officers in the planning of sound battle tactics.

A. ESSENTIAL CHARACTERISTICS OF A NAVAL BATTLE MODEL

A naval battle model must be characterized by simple measures of the aggregate combat power and staying power of the opposing forces as well as a means of expressing their

simultaneous attrition in battle. Additionally, the model must afford the user the opportunity to vary inputs concerning the allocation and deployment of platforms and the timing and direction of fire. This allows the user to analyze the impact of C^2 and effective scouting on a battle's dynamics. These are the characteristics of a model firmly grounded in Hughes' tactical theory.

B. INADEQUACY OF EXISTING FORCE-ON-FORCE ATTRITION MODELS

Lanchester-type force-on-force attrition models portray a battle with differential equations which represent the interaction of the opposing forces. Battle outcome is represented by the number of firing units, usually men, lost on each side. A key assumption underlying much of Lanchester theory, however, is that each firing unit fires the same kind of ammunition, at the same rate, with the same accuracy as all other firing units. In modelling land combat, this assumption may not seriously weaken the model since the deviation of the principal combatant's (soldier, tank, or artillery piece) combat power, rate of fire, and accuracy from the values embodied in the model are probably not great. Naval vessels (platforms), however, differ greatly in armament and ability to take punishment. It is, therefore, unrealistic to model heterogeneous mixes of platforms as homogeneous "firing units". Additionally, Lanchester-type models are inadequate for representing the processes of scouting and C^2 since their focus is strictly on attrition.

C. PROBLEMS OF VALIDATION

Most battle models have a credibility problem. This stems from the fact that no serious attempt has been made to validate them. According to Clayton Thomas [Ref. 2] validation is a problematic issue:

> ...validation involves testing the agreement of a model...with reality. One is required, therefore, to establish what is "reality" and what constitutes "adequate agreement", and to specify what sort of pronouncements are to be made in the respective cases of agreement and non-agreement. Each of these steps, even in the simplest case...poses fundamental and profound difficulties.

Determining what is to be the standard of reality is perhaps the most difficult problem encountered in the validation process. The two primary candidates are exercise results and historical combat data. Exercise results have the virtue of being drawn from a designed experiment. Therefore, they are usually complete, specific, and easily measured. Unfortunately, they are only as valid as the assumptions made in designing the experiment. Combat data have the virtue of being drawn from real life and are, therefore, free of underlying assumptions. The difficulties involved in researching combat data and verifying their accuracy, however, have caused many modelers to shy away from this approach. Yet, the fact that historical data are drawn from real life makes them, potentially, the most powerful tools for validating a battle model. Corroborating a battle model's results by comparing its prediction of the outcome of a

historical battle with the actual outcome would lend the model a high degree of credibility.

D. RESEARCH GOALS

A naval battle model which incorporates Hughes' tactical theory would help line naval officers put that theory into practice. The goals of this research, therefore, have been to:

- Develop a naval battle model which incorporates Hughes' tactical theory.
- Corroborate the model's results by comparing its predictions of historical battle outcomes with the actual outcomes.
- Demonstrate the model's value as a tactical planning tool by using it to evaluate the tactical options of one of the opponents in a historical naval battle.

This report describes the results of the research and is submitted to generate interest in the development and implementation of naval battle models for use in the fleet.

II. MODEL DESCRIPTION AND VERIFICATION

A. INTRODUCTION

This chapter will describe how the model and the computer program into which it is incorporated work and summarize the program verification procedure.

B. DEFINITIONS

The following terminology will be used throughout.

1. Firepower Kill

A platform which has suffered a firepower kill has suffered damage sufficient to prevent it from contributing combat power to the force.

2. 1000 Pound Bomb Equivalent (TPBE)

TPBE is a unit of destruction equal to the explosive power of 660 pounds of TNT (the explosive charge of a U.S. World War II - vintage 1000 pound bomb). The explosive power of all weapons will be expressed as multiples of 660 pounds of TNT contained in the warhead.

3. Theoretical Combat Power

Theoretical combat power is defined in two broad categories.

a. Continuous (FC)

FC is defined for individual platforms. It is the number of TPBE's which a platform's main battery guns can fire per minute.

b. Pulse (FP)

FP is defined for each "pulse weapon" type carried by a platform. Pulse weapons are weapons which deliver instantaneously a massive amount, or pulse, of firepower against a target. Such weapons include missiles, bombs, and torpedoes. The FP of a given weapon type is the number of TPBE's which the platform can fire in a single salvo.

4. Weapon Effectiveness

Weapon effectiveness is defined in the same categories as theoretical combat power.

a. Continuous (PC)

PC is defined for groups of platforms which fire as a single unit. It is the probability that a single shell fired from a group's main battery will strike its target.

b. Pulse (PP)

PP is defined for each type of pulse weapon fired by a group of platforms firing as a unit. It is the probability that a single pulse weapon will strike its target.

5. Effective Combat Power

a. Continuous (EFC)

EFC is defined for a group of platforms firing as a unit. It is the number of TPBE's, fired from a group's main battery guns, which strike their targets per minute.

b. Pulse (EFP)

EFP is defined for each pulse weapon type carried by a group of platforms firing as a unit. It is the number of TPBE's of a given weapon type, fired by a group in a single salvo, which strike their targets.

6. Staying Power (SP)

A platform's SP is defined as the number of TPBE hits necessary to inflict a firepower kill on that platform.

C. MODEL DESCRIPTION

1. General Description

Naval combat is modeled as a force-on-force attrition process. Component groupings of each force are portrayed as aggregations of the SP, FC, and FP values of their individual platforms. Attrition is computed in discrete time steps and is represented by the simultaneous degradation of each force's aggregate SP, FC, and FP over time.

2. Model Input Parameters--Description and Computation

a. Indices

i = Weapon

j = Platform

k = Group of platforms within a force

l = One of the two forces in a battle (A or B)

l' = The other force

b. Computation of Individual Platform Values

(1) Staying Power. The SP of a platform is computed as a function of its full load displacement as follows:

$$sp_{jkl} = 0.07 \times (\text{full load displacement})^{1/3} \tag{1}$$

This equation was derived from analysis of a data set of 75 platforms from World Wars I and II which were determined to have suffered firepower kills as a result of attacks by shells, bombs or torpedoes. A full discussion of this analysis is found in Appendix A.

(2) Theoretical Continuous Combat Power. The number of TPBE's which can be fired by a main battery gun per minute is computed as follows:

$$fc_{ijkl} = \left(\frac{\text{weight}}{660 \text{ lbs.}}\right) \times Wt_g \tag{2}$$

where:

fc_{ijkl} = number of TPBE's fired by gun i of platform j of group k, force l per minute.

weight = explosive weight in pounds of TNT which the gun fires per minute.

Wt_g = 2.5

The value of Wt_g was derived from the warship survivability analysis (Appendix A). It gives added weight to a gun's shell over a bomb of equal explosive weight apparently because a shell adds its much greater kinetic energy of impact to the destructive power of its explosive charge.

The FC of a platform is computed as follows:

$$fc_{jkl} = \sum_{i \text{ on } j} fc_{ijkl} \tag{3}$$

(3) Theoretical Pulse Combat Power. The number of TPBE's of a particular type of pulse weapon which a platform can fire in a single salvo is a function of the number and distribution of firing mechanisms of that weapon. A cruiser, for example, with four 24" torpedo tubes mounted on her port side and four on her starboard side can fire four 24" torpedoes per salvo. The FP of a pulse weapon type on a platform is computed as follows:

$$fp_{ijkl} = \left(\frac{\text{weight}}{660 \text{ lbs.}}\right) \times (\text{\# of weapons per salvo}) \times Wt_p \tag{4}$$

where:

fp_{ijkl} = number of TPBE's of pulse weapon type i which can be fired in a salvo by platform j, of group k, force 1.

weight = explosive weight in pounds of TNT of a warhead of pulse weapon type i.

Wt_p = 1.25 for torpedoes, 1.00 for bombs

The values of Wt_p were also derived from the survivability analysis (Appendix A). The additional weight for torpedoes over bombs seems justified by the fact that a torpedo damages a platform below her waterline, adding stability loss through flooding to the damage caused by the explosion. A weight for anti-ship missiles was not determined since the survivability analysis included no platforms damaged by ASM's.

c. Aggregation of Individual Platforms into Groups

A group is a subdivision of a force containing one or more of that force's platforms. All platforms in a group fire as a unit. The user determines the number and composition of each force's groups based on:

- Desired geographic disposition of a force's platforms.
- Sub-division of platforms by type (cruiser, destroyer, etc.).
- Tactical employment of the platforms (screen, scouts, main body, etc.).

The aggregate SP of each group is computed as follows

$$SP_{kl} = \sum_{\substack{j \text{ assigned} \\ \text{to group } k}} sp_{jkl} \qquad \forall k, \forall l \tag{5}$$

The aggregate FC of each group and the FP of each pulse weapon type in each group are computed as follows:

$$FC_{kl} = \sum_{\substack{j \text{ assigned} \\ \text{to group } k}} fc_{jkl} \qquad \forall k, \forall l \tag{6}$$

$$FP_{ikl} = \sum_{\substack{j \text{ assigned} \\ \text{to group } k}} fp_{ijkl} \quad \forall i, \forall k, \forall l \tag{7}$$

The PC of each group, PC_{kl}, and the PP of each pulse weapon type in each group, PP_{ikl}, are analogous to the attrition rate coefficients of a Lanchester-type model. Determination of their value is left to the user and should be based on experimental results, battle data, or estimation of own and enemy capabilities.

The EFC of each group and the EFP of each pulse weapon type in each group can now be expressed as follows:

$$EFC_{kl} = FC_{kl} \times PC_{kl} \quad \forall k, \forall l \tag{8}$$

$$EF_{ikl} = FP_{ikl} \times PP_{ikl} \quad \forall i, \forall k, \forall l \tag{9}$$

d. Additional Input Parameters

In addition to the SP, FC, and FP values of each group of both forces, and the associated PC and PP values, the user inputs into the model information concerning the times of commencement, duration, strength, and targets of each group's continuous and pulse fire.

(1) Continuous Fire. Input parameters for each group's continuous fire include:

- Time steps (one time step = one minute) of commencement and duration of fire.
- Which groups of the opposing force are the targets of this group's fire.

(2) Pulse Weapon Fire. Input parameters for each group's pulse weapon fire include:

- Time steps during which the weapons are fired.
- The pulse weapon types to be fired and the number of TPBE's (up to FP_{ikl}) of each type to be fired in each salvo.
- Which groups of the opposing force are the targets of each salvo.
- The number of time steps until impact of each salvo.

Finally, the user determines the duration of the engagement by specifying one of the following:

- Number of time steps to be run.
- The maximum acceptable percent loss in aggregate SP which each force will sustain before breaking off the engagement.

3. Model Variables

The aggregate *SP*, *FC* and *FP* values of all groups are recomputed at each time step, taking any attrition suffered in that time step into account. The variables which represent the simultaneous attrition to each group of both forces at each time step t are:

$SP_{kl}(t)$ = aggregate SP of group k, force l at time step t.

$FC_{kl}(t)$ = aggregate FC of group k, force l, at time step t.

$FP_{ikl}(t)$ = aggregate FP of weapon type i, group k, force l at time step t.

The total values for each force at time step t, therefore, are:

$$SP_l(t) = \sum_k SP_{kl}(t) \qquad (10)$$

$$FC_l(t) = \sum_k FC_{kl}(t) \qquad (11)$$

$$FP_l(t) = \sum_i \sum_k FP_{ikl}(t) \qquad (12)$$

4. Model Logic

The model is incorporated into a computer program coded in FORTRAN 77. Using the input parameters computed or specified by the user, the program:

- Starts and stops each group's continuous fire.
- Computes attrition to each group being fired on at each time step throughout the specified duration of the continuous fire.
- Fires pulse weapon salvoes and computes attrition to the target groups at each time step in the future when the salvoes strike their targets.
- Stops the engagement when the specified conditions for cessation are met.

A complete program listing is found in Appendix C.

The program computes attrition at each time step against those groups which are undergoing continuous fire or being struck by pulse weapons during that time step.

a. Continuous Fire Attrition

If continuous fire is taking place during the time step, the program sums the current aggregate SP values of the groups under attack:

$$TS = \sum_{\substack{k \text{ being} \\ \text{attacked} \\ \text{by } l'}} SP_{kl}\ (t-1) \qquad (13)$$

where:

$SP_{kl}(t-1)$ = SP of group k, force l at the end of time step t-1.

The program then computes the aggregate EFC of the attacking groups as follows:

$$AEFC = \sum_{\substack{k \text{ firing} \\ \text{from } l'}} FC_{kl'}(t-1) \times PC_{kl'} \tag{14}$$

where:

$FC_{kl'}(t-1)$ = FC of group k, force l' at the end of time step t-1.

Finally, the continuous fire loss percentage, LC, is computed as follows:

$$LC = \frac{AEFC}{TS} \tag{15}$$

LC is applied to the SP, FC, and FP values of the target groups. These values are updated for all groups of each force at each time step as follows:

$SP_{kl}(t)$	$= SP_{kl}(t-1) \times (1-LC)$	Vk under attack.	(16)
	$= SP_{kl}(t-1)$	otherwise.	(17)
$FC_{kl}(t)$	$= FC_{kl}(t-1) \times (1-LC)$	Vk under attack.	(18)
	$= FC_{kl}(t-1)$	otherwise.	(19)
$FP_{ikl}(t)$	$= FP_{ikl}(t-1) \times (1-LC)$	Vk under attack.	(20)
	$= FP_{ikl}(t-1)$	otherwise.	(21)

b. Pulse Fire Attrition

If a pulse weapon salvo is striking its target, the program sums the current SP values of the groups being attacked as before. The program then computes the aggregate EFP of the salvo as follows:

$$AEFP = PULSE_{l'} \times PP_{l'} \tag{22}$$

where:

$PULSE_{l'}$ = FP of the salvo fired from force l'.

$PP_{l'}$ = PP of the salvo fired from force l'.

Finally, the pulse fire loss percentage, LP, is computed as follows:

$$LP = \frac{AEFP}{TS} \tag{23}$$

LP is applied to the SP, FC, and FP values of the target groups. The updated values for all groups are computed in the same manner as following continuous fire attrition with LP replacing LC in equations (16), (18) and (20).

Once the updated values are computed for each group, the program computes the updated totals for each force using equations (10), (11) and (12). These totals, reflecting each force's aggregate SP, FC, and FP at the end of the time step, are printed in an output file for analysis by the user.

When the program stops the engagement, the total percentage lost of each force's SP, FC, and FP are computed and printed in the output file. A sample output file is found in Appendix C.

D. ALGORITHM VERIFICATION

The program was verified to be logically correct by calculating and inputting parameters designed to test the program's intricacies. The program's output was then compared to a hand-calculated result.

The input parameters included:

- Division of each force into more than one group.
- Assignment of different SP, FC, PC, FP, and PP values to each group.
- Variation of the combat interaction among the groups including one against one and two against two continuous and pulse fire.

The hand-calculated result, which represents how the algorithm should perform, and the model result, which represents how it actually performs, were found to be identical.

E. CONCLUSIONS

From the foregoing, it can be seen that a naval battle model has been developed which:

- Portrays naval forces as aggregations of the staying power and theoretical combat power of heterogeneous mixes of platforms.
- Models the engagement of these forces as a force-on-force attrition process with attrition suffered via continuous fire and/or through the impact of pulse weapons.
- Permits the user to vary inputs concerning the time, strength, target and duration of each force's fire in order to explore each force's tactical options.
- Computes attrition to the opposing forces simultaneously throughout the engagement and provides a result in terms of the percent SP, FC and FP lost by each force.

These are precisely the criteria which were set forth above for a naval battle model which embodies the essence of Hughes' tactical theory. It seems, therefore, that the model

is an appealing one. The acid test, however, is to use it to analyze actual data to determine if it performs as advertised.

III. GATHERING HISTORICAL DATA FOR MODEL VALIDATION

A. INTRODUCTION

Hixon and Hodges [Ref. 3] have succinctly stated a major inadequacy of current combat models:

> Combat simulation models have almost no empirical basis at all. One reason for this appears to be a general belief that relevant data don't exist. This apparent belief is false: historical archives are full of detailed data relevant to a range of combat activities....

One of the major goals of this work has been to take a step toward remedying this shortcoming by using historical naval battle data in the process of model validation. To achieve this goal, it was necessary to gather data relevant to the analysis. This chapter will describe the process of identifying the relevant data and summarize the data gathered.

B. NAVAL BATTLES TO BE STUDIED

The first step in the data gathering process was to determine the battles from which data would be drawn. Research was limited to twentieth century naval battles primarily because there are many published accounts of them. The battles were divided into three categories.

1. Continuous Fire Battles

Continuous fire battles are those in which gunfire was applied continuously by each side as the primary means of inflicting damage. The battles selected in this category are:

- Coronel, 01 November 1914.
- Falkland Islands, 08 December 1914.
- Dogger Bank, 24 January 1915.
- River Plate, 18 December 1939.
- Komandorski Islands, 25 March 1943.

2. Mixed Fire Battles

Mixed (continuous and pulse) fire battles are those in which one or both sides attempted (usually with success) to use pulse weapons to decisive effect. Gunfire was still used, however, to inflict considerable damage. Battles in this category are:

- Savo Island, 08 August 1942.
- Guadalcanal (Second Night), 14 November 1942.
- Tassafaronga, 30 November 1942.
- Kula Gulf, 06 July 1943.
- Vella Gulf, 06 August 1943.

3. Pulse Fire Battles

Pulse fire battles are those in which effective combat power was applied in pulses with continuous gunfire playing no part. Battles in this category are:

- Coral Sea, 07 May 1942.
- Midway, 04 June 1942.
- Eastern Solomons, 24 August 1942.
- Santa Cruz Islands, 26 October 1942.

These battles were selected because they allowed the model to be exercised in fundamentally different scenarios so that the degree of its potential for broad application could be determined.

C. IDENTIFICATION OF THE RELEVANT DATA

The process of identifying relevant data from a massive amount of published information involved answering four basic questions:

- What data are needed to compute each force's theoretical combat power?
- What data are needed to estimate each force's weapon effectiveness?
- What data are needed to compute each force's aggregate staying power?
- What data are needed to portray the interactions of forces in a battle and a battle's outcome?

Answering these questions provided a systematic approach to the gathering of data which greatly simplified the research process.

D. SUMMARY OF DATA GATHERED

1. Weapons Data

Relevant weapons data included those characteristics necessary to compute the FC or FP of a given weapon.

a. Continuous Weapons

Data was gathered on the main and secondary battery guns of all platforms in each battle. This data included:

- Bore diameter and calibre.
- TNT-equivalent explosive weight of shell.
- Rate of fire in rounds per minute.

b. Pulse Weapons

Data was gathered on platform-launched torpedoes, aircraft-launched torpedoes, and air-dropped bombs (as applicable) carried by each platform in each battle. These data included:

- Designation of the weapon (size, weight, etc.).
- TNT-equivalent explosive weight of the weapon's warhead.

2. Platform Data

Relevant data included those platform characteristics which, when coupled with associated weapon characteristics, permit the computation of a given platform's FC and FP values. These data included:

- Number and designation of all main and secondary battery guns.
- Designation, number and number per salvo of platform fired torpedoes.
- Number and weapon load-out of each type of aircraft carried.

Additionally, each platform's full load displacement was needed in order to compute its SP value.

3. Force Interaction

In addition to the characteristics of the weapons and platforms employed in each battle, data was gathered

pertaining to the interaction of the opposing forces. These data included:

- Origin, target, time of commencement and time of cessation of continuous fire.

- Number of each size of shell which was fired and number which hit their targets.

- Origin, target, time of fire and time of impact of each pulse weapon salvo.

- Type of weapon fired, number of weapons fired and number of weapons which struck their targets in each pulse weapon salvo (including air strikes).

- Duration (in minutes) of the battle.

4. Battle Outcome

Finally, data were gathered pertaining to the outcome of each battle including:

- Which platforms suffered firepcwer kills or were totally lost.

- Which platforms were damaged.

E. DATA SOURCES

Characteristics of weapons and platforms were drawn from modern technical works on historical naval forces. Particularly useful were Campbell [Ref. 4] and Gardner [Refs. 5 and 6]. Data on force interactions and battle outcomes were drawn from official and unofficial histories. All data were corroborated with at least two sources. A complete list of all works consulted is found in the bibliography.

F. CONCLUSION

The data collected on fourteen twentieth century naval battles were gathered to compute model input parameters representing the forces involved in each battle, their interaction in battle, and the outcome of each battle. The next chapter will discuss in detail how these data were used in the process of model validation.

IV. MODEL VALIDATION WITH HISTORICAL DATA

A. INTRODUCTION

Given the data from each of the 14 battles described in Chapter III, model input parameters were computed which represented as closely as possible the SP, FC, and FP values of the opposing forces as well as the interaction of those forces in the battle. The model was run using these input parameters and its results were compared with computed values representing each battle's actual outcome. Discrepancies were noted and explained and the model was revised as necessary. Finally, conclusions were drawn as to the model's validity.

This chapter will discuss this analysis, its results and the conclusions drawn from it.

B. DERIVING MODEL INPUT PARAMETERS FROM HISTORICAL DATA

1. Determining the Component Groupings of Each Force's Platforms

The composition of the component groupings of each force's platforms was determined based on the following criteria:

- The tactical disposition of each force as it actually existed in the battle.
- Which platforms fired weapons in the battle.
- Which platforms were the targets of the opposing force's fire.

- Whether the platforms in the group had the same main battery guns.

The last item was only a consideration for those platforms of the force which actually fired their guns.

2. Computation of Initial Values for Each Group

a. Theoretical Continuous Combat Power

The FC of each component group was determined by computing the value for all main battery guns on each platform of the group and then summing the values of all the platforms. Secondary battery guns were included only if they were fired with any effect in the battle.

b. Theoretical Pulse Combat Power

FP was determined by computing the value for each pulse weapon type on each platform and then summing the values of each type for all of the platforms.

c. Continuous Weapon Effectiveness

Each group's PC was estimated by taking the ratio of the number of its shells which hit their targets in the battle to the number of shells fired. If the number of shells fired could not be found in the historical accounts, it was estimated for each group as follows:

$$NS_{kl} = NMBG_{kl} \times MROF \times DOF_{kl} \tag{1}$$

where:

NS_{kl} = estimated number of shells fired by the main battery guns of group k, force l.

$NMBG_{kl}$ = number of main battery guns carried by all platforms in group k, force l.

$MROF$ = maximum rate of fire (in shells per minute) of a main battery gun.

DOF_{kl} = duration of fire of the group's guns (in minutes) as found in the historical accounts.

d. Pulse Weapon Effectiveness

PP of each pulse weapon type in each group was estimated by taking the ratio of the number of the group's weapons which struck their targets in the battle to the total number of weapons fired. If the total number of weapons fired could not be found in the historical accounts, it was estimated by assuming that, for each salvo, the group fired the maximum number possible in a single salvo.

e. Staying Power

Each platform's SP was computed using equation (1) of Chapter II. Each group's aggregate SP was determined by summing the SP values of all platforms in the group.

3. Determining Time of Commencement and Duration of Each Group's Continuous Fire

The time of commencement of a group's continuous fire was taken directly from the historical account of the battle under consideration. The duration of fire, however, was often more difficult to determine. While the historical accounts usually give the commencement and cessation times of each group's fire, they are often unclear as to how intermittent the fire was during that interval. It was, therefore, necessary to estimate duration of fire as follows:

$$DOF_{kl} = \frac{NS_{kl}}{NMBG_{kl} \times MROF} \qquad (2)$$

If the number of shells fired, NS_{kl}, was not available, duration of fire was estimated to be the number of minutes between the given times of commencement and cessation under the assumption that all guns that could bear fired continuously during this interval at their maximum firing rates.

4. Determining Time of Fire, Time of Impact and Theoretical Combat Power of Pulse Weapons Salvoes

The times of fire and times of impact of a group's pulse weapon salvoes were taken directly from the historical accounts of the battle under consideration. The FP of each salvo was computed using the type and number of pulse weapons fired in the salvo.

C. COMPUTING VALUES REPRESENTING A BATTLE'S ACTUAL OUTCOME

Each battle's actual outcome was expressed in terms of the percent FC and FP lost by each force. It was not, however, possible to determine these percentages precisely since it was unclear in most historical accounts to what extent the damage a platform received contributed to loss of combat power unless the platform suffered at least a firepower kill. It was, however, possible to establish lower and upper bounds on each force's loss of FC and FP. The lower limits of the resulting theoretical combat power loss intervals represent the percent

theoretical combat power loss intervals represent the percent of a force's FC or FP carried by all of the force's platforms suffering at least a firepower kill during a given battle. The upper limits represent the percent of FC or FP carried by all of the force's platforms suffering at least some damage in the battle.

1. Computing a Force's FC Loss Interval

The lower limit of the FC loss interval for a given force in a given battle was computed as follows:

$$LCL_l = \frac{SLCW_l}{TCW_l} \tag{3}$$

where:

LCL_l = The lower limit of the FC loss interval of force l.

$SLCW_l$ = The TNT explosive weight which could be fired per minute by all main battery guns of force l's platforms which suffered at least a firepower kill.

TCW_l = The TNT explosive weight which could be fired per minute by all main battery guns of all platforms in force l.

The upper limit was computed as follows:

$$UCL_l = \frac{SLCW_l + DCW_l}{TCW_l} \tag{4}$$

where:

UCL_l = The upper limit of the FC loss interval of force l.

DCW_l = The TNT explosive weight which could be fired by all force 1 platforms which were damaged but were not sunk or did not suffer firepower kill.

2. Computing a Force's FP Loss Interval

The lower limit of the FP loss interval for a force in a given battle was computed as follows:

$$LPL_l = \frac{SLPW_l}{TPW_l} \tag{5}$$

where:

LPL_l = The lower limit of the FP loss interval of force 1.

$SLPW_l$ = The TNT explosive weight of all pulse weapons of all types which could be fired in a single salvo by all force 1 platforms which suffered at least a firepower kill.

TPW_l = The TNT explosive weight of all pulse weapons of all types which could be fired in a single salvo by all force 1 platforms.

The upper limit was computed as follows:

$$UPL_l = \frac{SLPW_l + DPW_l}{TPW_l} \tag{6}$$

where:

UPL_l = The upper limit of the FP loss interval of force 1.

DPW_l = The TNT explosive weight of all pulse weapons of all types which could be fired in a single salvo by all force 1 platforms which were damaged but were not sunk or did not suffer firepower kill.

D. COMPARING MODEL RESULTS WITH COMPUTED ACTUAL BATTLE OUTCOMES

To test the credibility of the model's results, the following steps were performed for each battle:

- Model input parameters derived from the historical accounts of the battle were computed using the procedures discussed above.
- An FC loss interval and an FP loss interval were computed for each force.
- The model was run using the parameters computed from historical data and the resulting loss in each force's FC and FP, as predicted by the model, were recorded.

The model was deemed to have produced a credible result if, for both forces:

- The predicted percent loss in total FC fell within the FC loss interval.
- The predicted percent loss in total FP fell within the FP loss interval.

If any of the model values fell outside the intervals an attempt was made to discover the cause to determine if:

- The discrepancy was the result of a weakness in the model's assumptions indicating a need to revise the model or
- The discrepancy was the result of some anomaly of nature which did not threaten the model's assumptions.

If a weakness was found in the model's assumptions, they were revised and the validation process was repeated to determine if the revised model produced a credible result.

The strength of this validation process lies in the fact that computation of the theoretical combat power loss intervals involved no underlying, unsupportable assumptions. They were computed using data which were easily observed in the historical accounts of each battle.

The weakness of the process stems from the fact that it was not possible to determine a single value representing the battle's actual outcome for those battles in which some ships were damaged but did not suffer a firepower kill. While the model assumes that loss of theoretical combat power is proportional to the number of TPBE hits received, the extent to which the number of hits received contributes to loss of theoretical combat power is not observable from the historical accounts. Hits may not damage guns or pulse weapon launchers directly but may damage supporting "systems" such as fire control, propulsion, structural integrity, and personnel. While damage to these systems degrades combat power, the extent of this degradation is unclear. Therefore, the computation of loss intervals was chosen as the most precise representation of theoretical combat power loss which could be made. Unfortunately, these intervals may be fairly wide. While it is clear that the model's results should fall within

them, it is not possible to make any other assertions about the credibility of the model's results.

The conclusion, therefore, is that the validation process is limited. It does permit conclusions to be drawn, however, about the credibility of the model's results and is, therefore, a first step in the continuous process of validation.

E. INDIVIDUAL BATTLE ANALYSES

The validation process discussed above was conducted using data from the fourteen naval battles. Summarized below are the input parameters and validation results for each battle. Each summary includes the following:

- Participating platforms listed by the groups into which each force was organized.
- Brief summary of the significant events of the battle.
- Computation of the model's input parameters and theoretical combat power loss intervals.
- Tables of input parameters.
- Comparison of model results with the loss intervals.
- Conclusions.

The characteristics of the platforms and weapons employed in each battle are found in Appendix B. These characteristics were used to compute model input parameters not specifically discussed below. Table 4-1 provides a key to reading the subsequent tables found in this chapter.

TABLE 4-1 KEY TO ABBREVIATIONS USED IN INPUT PARAMETER TABLES

ABBREVIATION	DESCRIPTION
FC	Theoretical continuous combat power.
PC	Continuous weapon effectiveness.
FP1 (FP2, FP3)	Theoretical pulse combat power of pulse weapon type 1 (2 or 3).
PP1 (PP2, PP3)	Pulse weapon effectiveness of pulse weapon type 1 (2 or 3).
SP	Staying power.
GF	Groups firing.
GBA	Groups being attacked.
TOF	Time of fire.
DOF	Duration of fire.
TUI	Time until impact.
TP	Pulse weapon type.
E	Theoretical pulse combat power of pulse weapon salvo fired.

1. Battle of Coronel - 01 November 1914

Bennet [Ref. 7] was the primary source of data on this battle. Corbett [Ref. 8] was used as a secondary source.

a. Force Disposition

Table 4-2-A summarizes the disposition of forces in the battle.

TABLE 4-2-A FORCES INVOLVED IN THE BATTLE OF CORONEL

FORCE	GROUP	PLATFORMS
A (BRITISH)	1	GOOD HOPE, MONMOUTH
	2	GLASGOW
B (GERMAN)	1	SCHARNHORST, GNEISENAU
	2	LEIPZIG, DRESDEN

b. Significant Events

Table 4-2-B summarizes the battle's significant events.

TABLE 4-2-B SIGNIFICANT EVENTS OF THE BATTLE OF CORONEL

TIME	EVENT
1620	GLASGOW sights German squadron.
1630	LEIPZIG sights British squadron.
1900	SCHARNHORST and GNEISENAU open fire on GOOD HOPE and MONMOUTH.
1906	GOOD HOPE, MONMOUTH and GLASGOW return fire.
1920	DRESDEN and LEIPZIG open fire on GLASGOW and drive her out of the engagement.
2000	GOOD HOPE sinks.
2130	MONMOUTH sinks.

c. Computation of Input Parameters

(1) Continuous Weapon Effectiveness. SCHARNHORST and GNEISENAU fired approximately 1800 shells scoring 50 hits. Their PC was, therefore, estimated to be 0.028. DRESDEN and LEIPZIG fired their 4.1" guns for two minutes resulting in an estimate of 400 shells fired. Five hits were scored and

therefore, their PC was estimated to be 0.012. GLASGOW fired for 15 minutes resulting in an estimate of 210-6" shells fired. Six hits were scored resulting in an estimated PC of 0.028. GOOD HOPE and MONMOUTH fired with no effect throughout the battle.

(2) Duration of Continuous Fire. SCHARNHORST and GNEISENAU, having fired 1800 shells, were estimated to have fired for 28 minutes.

All input parameters are summarized in Tables 4-2-C and 4-2-D.

TABLE 4-2-C CORONEL--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FC	PC	SP
A (BRITISH)	1	7.27	0.000	3.21
	2	0.42	0.028	1.23
B (GERMAN)	1	4.32	0.028	3.30
	2	4.33	0.012	2.23

TABLE 4-2-D CORONEL--SUMMARY OF CONTINUOUS FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	DOF
A (BRITISH)	1	2	1	6	15
B (GERMAN)	1	1	1	1	28
	2	2	2	19	2

d. Computation of Theoretical Combat Power Loss Intervals

GOOD HOPE and MONMOUTH were destroyed and GLASGOW was damaged at Coronel resulting in an FC loss interval of 94.18% - 100.00%. SCHARNHORST and GNEISENAU were damaged resulting in an FC loss interval for the German force of 0.00% - 49.92%.

e. Comparison of Model Results with the Loss Intervals and Conclusions

Table 4-2-E summarizes the result of the comparison.

TABLE 4-2-E CORONEL--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LCL	% FC LOST	UCL
A (BRITISH)	94.18	94.77	100.00
B (GERMAN)	0.00	2.67	49.92

Since the model results fall within the computed intervals, there is no reason to question them.

2. Battle of Falkland Islands - 08 December 1914

Bennet [Ref. 7] was the primary source of data on this battle. Corbett [Ref. 8] was used as a secondary source.

a. Force Disposition

Table 4-3-A summarizes the forces involved in the battle.

TABLE 4-3-A FORCES INVOLVED IN THE BATTLE OF FALKLAND ISLANDS

FORCE	GROUP	PLATFORMS
A (BRITISH)	1	INVINCIBLE, INFLEXIBLE
B (GERMANS)	1	SCHARNHORST, GNEISENAU

b. Significant Events

Table 4-3-B summarizes the battle's significant events.

TABLE 4-3-B SIGNIFICANT EVENTS OF THE BATTLE OF FALKLAND ISLANDS

TIME	EVENT
0756	German squadron, closing the British colony in the Falkland Islands for a raid, sights a British battlecruiser squadron anchored in the harbor. At the same time, British lookouts sight the German ships.
1250	British battlecruisers come within firing range of SCHARNHORST and GNEISENAU and open fire. The German cruisers immediately return fire.
1320	German light cruisers speed away with British cruisers in pursuit.
1400	British battlecruisers disengage and maneuver for better firing position.
1445	British battlecruisers reopen fire.
1455	SCHARNHORST and GNEISENAU reopen fire.
1617	SCHARNHORST sinks.
1800	GNEISENAU sinks.

c. Computation of Input Parameters

(1) Continuous Weapon Effectiveness. The British battlecruisers fired 1200-12" rounds, scoring 5 hits. PC, therefore, was estimated to be 0.042. No data was available on the Germans' duration of fire or number of shells fired. German PC was, therefore, assumed to equal 0.028 (the PC displayed at Coronel).

(2) Duration of Continuous Fire. The battle was essentially a fight to the death between the British and Germans so fire was continued in the model until one side was eliminated (TTD). All input parameters are summarized in tables 4-3-C and 4-3-D.

TABLE 4-3-C FALKLAND ISLANDS--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FC	PC	SP
A (BRITISH)	1	8.21	0.042	3.82
B (GERMAN)	1	4.32	0.028	3.30

TABLE 4-3-D FALKLAND ISLANDS--SUMMARY OF CONTINUOUS FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	DOF
A (BRITISH)	1	1	1	1	TTD
B (GERMAN)	1	1	1	1	TTD

d. Computation of Theoretical Combat Power Loss Intervals

The Germans lost both SCHARNHORST and GNEISENAU so the interval shrinks to a point equal to 100%. Damage on the

British side was sustained by INVINCIBLE resulting in an FC loss interval of 0% - 50%.

e. Comparison of Model Results with the Loss Intervals and Conclusions

The results of the comparison are summarized in Table 4-3-E.

TABLE 4-3-E FALKLAND ISLANDS--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LCL	% FC LOST	UCL
A (BRITISH)	0.00	17.32	50.00
B (GERMAN)	100.00	100.67	100.00

Since the results fall within the computed intervals, there is no reason to question them.

3. Battle of Dogger Bank - 24 January 1915

The primary source for data on this battle was Campbell [Ref. 9]. Corbett [Ref. 8] was the secondary source.

a. Force Disposition

Table 4-4-A summarizes the disposition of forces in the battle.

TABLE 4-4-A FORCES INVOLVED IN THE BATTLE OF DOGGER BANK

FORCE	GROUP	PLATFORMS
A (British)	1	LION
	2	PRINCESS ROYAL
	3	TIGER
	4	NEW ZEALAND
	5	INDOMITABLE
B (German)	1	SEYDLITZ
	2	DERFFLINGER
	3	MOLTKE

The German armored cruiser BLUCHER was not included in the German force since she was not considered capable of seriously damaging the British battlecruisers.

b. Significant Events

Table 4-4-B summarizes the battle's significant events.

TABLE 4-4-B SIGNIFICANT EVENTS OF THE BATTLE OF DOGGER BANK

TIME	EVENT
0730	British and German battlecruiser squadrons sight each other.
0906	LION and TIGER open fire on German battlecruisers.
0912	German battlecruisers open fire on British battlecruisers.
0933	Due to confused signals, *TIGER shifts fire* to SEYDLITZ, leaving MOLTKE untouched.
	LION concentrates fire on SEYDLITZ.
0933	PRINCESS ROYAL engages and is engaged by DERFFLINGER.
	MOLTKE fires unopposed on LION and TIGER.
0950	Large explosion on SEYDLITZ causes her to lose her aft turrets.
1000	LION, TIGER, SEYDLITZ and MOLTKE fire only infrequently due to poor visibility.
1010	LION, TIGER, SEYDLITZ and MOLTKE resume continuous fire.
1045	INDOMITABLE enters the engagement, firing on BLUCHER.

1050 LION falls out of the engagement. Misleading signals from flagship leads British battlecruisers to break off and concentrate on BLUCHER.

c. Computation of Input Parameters

(1) Estimated Number of Shells Fired. Campbell [Ref. 9] states that capital ship guns seldom fired at a rate greater than one shell per minute during World War I. Estimates of the number of shells fired by each ship, therefore, were made on the assumption that the firing rates of all main battery guns were one round per minute.

LION fired during a period of 96 minutes resulting in an estimate of 768 shells fired. PRINCESS ROYAL fired during a period of 101 minutes resulting in an estimate of 808 shells fired. SEYDLITZ and MOLTKE fired during a period of 95 minutes resulting in an estimate of 950 shells fired by each platform.

(2) Duration of Continuous Fire. Since FC of each platform is computed on the basis of the maximum firing rate of the platform's main battery guns, the input parameters to the model pertaining to duration of fire were computed using the estimated number of shells fired (computed above) and the maximum rate of fire of each platform's main battery guns.

LION was estimated to have fired 768 shells and, therefore, to have fired the equivalent of 64 minutes at her maximum firing rate. PRINCESS ROYAL was estimated to have fired 808 shells and, therefore, to have fired the equivalent

of 67 minutes at her maximum firing rate. SEYDLITZ and MOLTKE were each estimated to have fired 950 shells and, therefore, to have fired the equivalent of 63 minutes at their maximum firing rates.

Each platform's estimated duration of fire was distributed over the platform's firing events in the same proportions as the actual, observed firing intervals.

(3) Continuous Weapon Effectiveness. LION and PRINCESS ROYAL each scored three hits resulting in an estimated PC for both of 0.004. SEYDLITZ and MOLTKE together scored 22 hits resulting in an estimated PC of 0.012.

No other battlecruisers fired with effect in this engagement. All input parameters are summarized in Tables 4-4-C and 4-4-D.

TABLE 4-4-C DOGGER BANK--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FC	PC	SP
A (British)	1	5.08	0.004	2.18
	2	5.08	0.004	2.18
	3	5.08	0.000	2.32
	4	4.11	0.000	1.97
	5	4.11	0.000	1.91
B (German)	1	2.81	0.012	2.14
	2	2.01	0.000	2.20
	3	2.81	0.012	2.07

TABLE 4-4-D DOGGER BANK--SUMMARY OF CONTINUOUS FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	DOF
A (British)	1	1	1,3	1	37
	2	2	2	6	67
	3	1	1	66	27
B (German)	1	1,3	1,3	7	36
	2	2	1	66	27

d. Computation of Theoretical Combat Power Loss Intervals

LION suffered a firepower kill in the battle and TIGER was damaged resulting in an FC loss interval of 24.37% - 48.74%. SEYDLITZ lost four of her main battery guns while DERFFLINGER was also damaged. The FC loss interval for the German force is, therefore, 14.73% - 63.17%.

e. Comparison of Model Results with the Theoretical Combat Power Loss Intervals and Conclusions

The results of the comparison are summarized in Table 4-4-E.

TABLE 4-4-E DOGGER BANK--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LCL	% FC LOST	UCL
A (BRITISH)	24.37	30.20	48.74
B (GERMAN)	14.73	28.83	63.17

Since the model's results fall within the computed intervals, there is no reason to question them.

4. Battle of River Plate - 13 December 1939

The primary source for data on this battle was Pope [Ref. 10]. Stephen [Ref. 11] was the secondary source.

a. Force Disposition

Table 4-5-A summarizes the disposition of forces in the battle.

TABLE 4-5-A FORCES INVOLVED IN THE BATTLE OF RIVER PLATE

FORCE	GROUP	PLATFORMS
A (BRITISH)	1	EXETER
	2	AJAX, ACHILLES
B (GERMAN)	1	GRAF SPEE

b. Significant Events

Table 4-5-B summarizes the battle's significant events.

TABLE 4-5-B SIGNIFICANT EVENTS OF THE BATTLE OF RIVER PLATE

TIME	EVENT
0552	GRAF SPEE sights British squadron.
0610	British squadron sights GRAF SPEE.
0617	GRAF SPEE opens fire on EXETER.
0618	British squadron opens fire on GRAF SPEE.
0730	EXETER falls out of the engagement. GRAF SPEE shifts fire to AJAX and ACHILLES.
0740	British break off the engagement.

c. Computation of Input Parameters

(1) Duration of Continuous Fire. EXETER fired 193 shells resulting in an estimated duration of fire of six minutes. AJAX and ACHILLES together fired 1984 shells resulting in an estimated duration of fire of 25 minutes. GRAF SPEE fired 410 shells resulting in an estimated duration of fire of 20 minutes.

Each platform's estimated duration of fire was distributed over the platform's firing events in the same proportion as the actual, observed firing intervals.

(2) Continuous Weapon Effectiveness. EXETER scored 3 hits resulting in an estimated PC of 0.016. AJAX and ACHILLES scored 17 hits resulting in an estimated PC of 0.009. GRAF SPEE scored 9 hits resulting in an estimated PC of 0.022.

All input parameters are summarized in Tables 4-5-C and 4-5-D.

TABLE 4-5-C RIVER PLATE--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FC	PC	SP
A (British)	1	2.53	0.016	1.54
	2	2.42	0.009	2.96
B (German)	1	3.91	0.022	1.78

TABLE 4-5-D RIVER PLATE--SUMMARY OF CONTINUOUS FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	DOF
A (British)	1	1,2	1	2	6
	2	2	1	8	19
B (German)	1	1	1	1	18
	2	1	2	18	2

d. Computation of Theoretical Combat Power Loss Intervals

EXETER suffered a firepower kill in the battle and ACHILLES was damaged resulting in an FC loss interval of 51.14% - 75.57%. GRAF SPEE was damaged resulting in an FC loss interval of 0.00% and 100.00%. Unfortunately, this interval will not yield a very informative result.

e. Comparison of Model Results with the Loss Intervals and Conclusions

The results of the comparison are summarized in Table 4-5-E.

TABLE 4-5-E RIVER PLATE--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LCL	% FC LOST	UCL
A (BRITISH)	51.14	44.23	75.57
B (GERMAN)	0.00	35.46	100.00

As can be seen in the table, a major discrepancy exists between the model's result and the FC loss interval for the British force. Investigation revealed that the discrepancy was caused by the fact that EXETER was knocked out of the battle with fewer TPBE hits than predicted by the

survivability model (Appendix A). This result, however, does not suggest a major weakness in the model. EXETER's early loss could have been the result of factors peculiar to the platform such as:

- Poor damage control.
- Crew inefficiency due to lack of battle experience.
- Poor command and control due to lack of experience.
- Ship design weaknesses.

In other words, EXETER's early loss was an anomaly attributable to EXETER herself rather than to the model. If any criticism can be aimed at the model, therefore, it is that it does not incorporate assumptions addressing the potential causes of EXETER's loss listed above. Incorporation of such detailed assumptions, however, would over-complicate the model and, therefore, diminish its utility. Users of the model, however, should be aware that it does not incorporate these issues.

5. Battle of Coral Sea - 08 May 1942

The primary source for data on this battle was Wilmont [Ref. 12]. Morison [Ref. 13] and Dull [Ref. 14] were secondary sources.

a. Force Disposition

Table 4-6-A summarizes the disposition of forces in the battle.

TABLE 4-6-A FORCES INVOLVED IN THE BATTLE OF CORAL SEA

FORCE	GROUP	PLATFORMS
A (U.S.)	1	LEXINGTON
	2	YORKTOWN
B (JAPANESE)	1	SHOKAKU
	2	ZUIKAKU

Only carriers were considered in this and subsequent pulse fire battles since it was the carriers which possessed the tactically significant combat power and which were the targets of each force's attack.

b. Significant Events

Table 4-6-B summarizes the battle's significant events.

TABLE 4-6-B SIGNIFICANT EVENTS OF THE BATTLE OF CORAL SEA

TIME	EVENT
0820	U.S. search aircraft locate Japanese carriers.
0822	Japanese search aircraft locate U.S. carriers.
0907-1000	U.S. carriers launch an air strike consisting of 28 Dauntless dive bombers (1-1000 lb. HC bomb each) and 20 Devastator torpedo bombers (1-22.4" torpedo each).
0915-1015	Japanese launch a strike consisting of 33 Val dive bombers (1-250 kg. SAP bomb each) and 18 Kate torpedo bombers (1-18" torpedo each).
1057	24 Dauntlesses and 9 Devastators attack Japanese carriers. SHOKAKU hit by 2-1000 lb. HC bombs.

1120	Japanese strike reaches U.S. carriers. LEXINGTON hit by 2-250 kg. SAP bombs and 2-18" torpedoes. YORKTOWN hit by 1-250 kg. SAP bomb.
1140	11 Devastators and 4 Dauntlesses from a second LEXINGTON strike attack. SHOKAKU receives one additional 1000 lb. HC bomb hit.

c. Computation of Input Parameters.

LEXINGTON and YORKTOWN launched 46 Dauntlesses, each with a single 1000 lb. bomb. Three hits were scored resulting in an estimated PP of 0.065. SHOKAKU and ZUIKAKU launched 33 Vals, each armed with a 250 kg. bomb. Three hits were scored resulting in an estimated PP of 0.091. Additionally, the Japanese carriers launched 18 Kates, each armed with an 18" torpedo. Two hits were scored resulting in an estimated PP for this weapon of 0.111.

Model input parameters are summarized in Tables 4-6-C and 4-6-D. For the U.S. force, pulse weapon type one (FP1, PP1) is the 1000 lb. HC bomb, pulse weapon type two (FP2, PP2) is the 500 lb. HC bomb and pulse weapon type three (FP3, PP3) is the 22.4" torpedo. For the Japanese force, pulse weapon type one (FP1, PP1) is the 250 kg. SAP bomb and pulse weapon type two (FP2, PP2) is the 18" torpedo.

TABLE 4-6-C CORAL SEA--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FP1	PP1	FP2	PP2	FP3	PP3	SP
A (U.S.)	1	17.00	0.065	7.91	0.000	8.34	0.000	2.42
	2	17.00	0.065	7.91	0.000	7.58	0.000	2.07
B (JAPAN)	1	3.68	0.091	12.10	0.111			2.42
	2	3.46	0.091	11.17	0.111			2.24

TABLE 4-6-D CORAL SEA--SUMMARY OF PULSE FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	TUI	TP	E
A (U.S)	1	1,2	1	47	111	1	24.00
	2	1,2	1	47	154	1	4.00
B (JAP)	1	1,2	1,2	55	125	1	7.14
	2	1,2	1	55	125	2	16.76

d. Computation of Theoretical Combat Power Loss Intervals

LEXINGTON was lost in the battle while YORKTOWN was damaged resulting in an FP loss interval of 50.48%-100.00% SHOKAKU suffered a firepower kill resulting in an FP loss value of 51.90%.

e. Comparison of Model Results with the Theoretical Combat Power Loss Intervals and Conclusions.

The results of the comparison are summarized in Table 4-6-E.

TABLE 4-6-E CORAL SEA--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LPL	% FP LOST	UPL
A (U.S.)	50.48	53.35	100.00
B (JAPAN)	51.90	51.90	51.90

Since the model's results fall within the computed intervals, there is no reason to question them.

6. Battle of Midway--04 June 1942

The primary source for data on this battle was Wilmont [Ref. 12]. Morison [Ref. 13] and Dull [Ref. 14] were secondary sources.

a. Force Disposition.

Table 4-7-A summarizes the disposition of forces in the battle.

TABLE 4-7-A FORCES INVOLVED IN THE BATTLE OF MIDWAY

FORCE	GROUP	PLATFORMS
A. (U.S.)	1	YORKTOWN
	2	ENTERPRISE, HORNET
B (JAPAN)	1	KAGA, AKAGI, SORYU
	2	HIRYU

b. Significant Events

Table 4-7-B summarizes the battle's significant events.

TABLE 4-7-B SIGNIFICANT EVENTS OF THE BATTLE OF MIDWAY

TIME	EVENT
0710	First U.S. sighting of Japanese carrier force.
0728	Float plane from Japanese carrier TONE sights the YORKTOWN task force.
0802	HORNET and ENTERPRISE launch a strike including 29 Devastators (1-22.4" torpedo each), 33 Dauntlesses (1-1000 lb. HC bomb each) and 34 Dauntless scouts (1-500 lb. HC bomb each).

0906	YORKTOWN launches a strike including 17 Dauntlesses (1-1000 lb. HC bomb each) and 12 Devastators (1-22.4" torpedo each).
0930-1015	29 Devastators from HORNET and ENTERPRISE attack the Japanese carriers, no hits.
1026-1100	50 Dauntlesses and 30 Dauntless scouts attack the Japanese carriers. AKAGI takes two 1000 lb. bomb hits, KAGA takes four hits and SORYU takes two hits.
1100	HIRYU launches a strike consisting of 18 Vals (1-250 kg. SAP bomb each).
1200	HIRYU launches 10 Kate torpedo bombers (1-18" torpedo each).
	HIRYU Vals attacks YORKTOWN scoring three hits.
1430	HIRYU Kates attack YORKTOWN scoring two hits.
1530	ENTERPRISE and HORNET launch 24 Dauntlesses (1-1000 lb. HC bomb each).
1700	24 Dauntlesses attack HIRYU scoring three hits.

c. Computation of Input Parameters

YORKTOWN and ENTERPRISE launched 74 Dauntlesses, scoring 12-1000 lb. bomb hits. The resulting estimated PP is 0.162. HIRYU launched 18 Vals, scoring 3-250 kg. bomb hits. The resulting estimated PP is 0.167. Additionally, HIRYU launched 10 Kates, scoring 2-18" torpedo hits. The resulting estimated PP for this pulse weapon is 0.2.

Model input parameters are summarized in Tables 4-7-C and 4-7-D. For the U.S. force, pulse weapon type one (FP1, PP1) is the 500 lb. HC bomb, pulse weapon type two (FP2,

PP2) is the 1000 lb. HC bomb and pulse weapon type three (FP3, PP3) is the 22.4" torpedo. For the Japanese force, pulse weapon type one (FP1, PP1) is the 250 kg. SAP bomb and pulse weapon type two (FP2, PP2) is the 18" torpedo.

TABLE 4-7-C MIDWAY--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FP1	PP1	FP2	PP2	FP3	PP3	SP
A (U.S.)	1	8.85	0.000	18.00	0.162	9.86	0.000	2.07
	2	17.23	0.000	38.00	0.162	21.99	0.000	4.14
B (JAPAN)	1	11.67	0.000	63.31	0.000		0.000	6.33
	2	3.89	0.167	16.76	0.200		0.000	1.52

TABLE 4-7-D MIDWAY--SUMMARY OF PULSE FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	TUI	TP	E
A (U.S)	1	2	1	1	145	2	17.00
	2	1	2	1	145	2	16.00
	3	1	1	65	81	2	17.00
	4	2	2	470	91	2	24.00
B (JAP)	1	2	1	179	61	1	3.89
	2	2	1	259	91	2	9.31

d. Computation of Theoretical Combat Power Loss Intervals

YORKTOWN suffered a firepower kill resulting in an FP loss value of 32.29%. The Japanese lost all four of their carriers resulting in an FP loss value of 100.00%.

e. Comparison of Model Results with the Loss Intervals and Conclusions

The results of the comparison are summarized in Table 4-7-E.

TABLE 4-7-E MIDWAY--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LPL	% FP LOST	UPL
A (U.S.)	32.29	32.22	32.29
B (JAPAN)	100.00	100.00	100.00

As can be seen from the table, a minor discrepancy exists between the model's result and the FP loss value for the U.S. force. Investigation revealed that the discrepancy stems from the fact that the FP loss intervals are computed without the weights which the model assigns to torpedoes (see equation (4) Chapter II). The rationale for this is that it was desired that computation of the loss intervals involve no underlying assumptions. Unfortunately, for battles involving more than one pulse weapon type and uneven distribution of the pulse weapons among the various groups of a force, failure to assign the weights when computing the intervals leads to a small, artificial discrepancy like the one above. It is not felt, however, that this is a major problem since, in the case of the U.S. force at Midway, both values imply the complete loss of YORKTOWN.

7. Battle of Savo Island -- 08 August 1942

The primary sources for data on this battle were Morison [Ref. 15] and Dull [Ref. 14]. Newcomb [Ref. 16] was used as a secondary source.

a. Force Disposition

Table 4-8-A summarizes the disposition of the forces in this battle.

TABLE 4-8-A FORCES INVOLVED IN THE BATTLE OF SAVO ISLAND

FORCE	GROUP	PLATFORMS
A (US)	1	VINCENNES, ASTORIA, QUINCY
	2	HELM, WILSON
	3	CHICAGO, CANBERRA
	4	PATTERSON, BAGLEY
	5	SAN JUAN, HOBART
	6	MONSSEN, BUCHANON
	7	BLUE, RALPH TALBOT
B (JAPAN)	1	AOBA, KAKO, KINUGASA, FURUTAKA, CHOKAI
	2	TENRYU, YUBARI, YUNAGI

b. Significant Events

Table 4-8-B summarizes the battle's significant events.

TABLE 4-8-B SIGNIFICANT EVENTS OF THE BATTLE OF SAVO ISLAND

TIME	EVENT
0136	Japanese force sights U.S. Southern Force (groups 3 and 4).
0138	Japanese fire 17-24" torpedoes.
0143	Japanese cruisers open fire on Southern Force cruisers.

0143 CANBERRA struck by 2-24" torpedoes and a total of 24-8" shells.

0147 CHICAGO hit by 1-24" torpedo but manages to open fire (ineffectively) on the Japanese squadron.

0148 CHICAGO falls out of the battle.

Japanese fire 16-24" torpedoes at U.S. Northern Force (groups 1 and 2).

Japanese cruisers open fire on U.S. Northern Force.

0154 U.S. Northern Force cruisers open fire on the Japanese.

0153 VINCENNES struck by several 8" shells.

KINUGASA struck by 1-8" shell.

0155 VINCENNES struck by 3-24" torpedoes, QUINCY hit by 1-24" torpedo.

0155 ASTORIA struck by numerous 8" shells but scores 2-8" hits on CHOKAI.

0156 Japanese force fires a complete salvo of 24" torpedoes.

0200 Japanese cease fire on Northern Force.

0213 BLUE and RALPH TALBOT engage the Japanese. RALPH TALBOT hit by 4-8" shells.

c. Computation of Input Parameters

(1) Duration of Continuous Fire. The three U.S. Northern Force cruisers fired 107-8" shells. Estimated duration of fire, therefore, is one minute. BLUE and RALPH TALBOT fired 385-5" shells. Estimated duration of fire of the two destroyers, therefore, is two minutes. The five Japanese heavy cruisers fired 1020-8" shells. Estimated

heavy cruisers fired 1020-8" shells. Estimated duration of fire of these cruisers, therefore, is eight minutes.

(2) Weapon Effectiveness. The U.S. Northern Force cruisers scored four hits resulting in an estimated PC of 0.037. BLUE and RALPH TALBOT scored one hit resulting in an estimated PC of 0.003. The Japanese heavy cruisers scored 92 hits resulting in an estimated PC of 0.09. Finally, the entire Japanese force fired 61-24" torpedoes, scoring 7 hits. The resulting estimated PP is 0.115. No other platforms fired with effect in this battle.

Model input parameters are summarized in Tables 4-8-C, 4-8-D and 4-8-E. For the U.S. force, pulse weapon type one (FP1, PP1) is the U.S. 21" torpedo and pulse weapon type two (FP2, PP2) is the British 21" torpedo. For the Japanese force, pulse weapon type one (FP1, PP1) is the 24" "Long Lance" torpedo.

TABLE 4-8-C SAVO ISLAND--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FC	PC	FP1	PP1	FP2	PP2	SP
A (U.S.)	1	9.03	0.037					4.89
	2	4.17	0.000	24.93	0.000			1.84
	3	6.38	0.000					3.31
	4	4.17	0.000	24.93	0.000			1.84
	5	11.70	0.000	6.23	0.000	5.51	0.000	2.90
	6	5.21	0.000	31.17	0.000			1.88
	7	4.17	0.003	24.93	0.000			1.84
B (JAPAN)	1	11.85	0.090	48.02	0.115			7.88
	2	2.28	0.000	8.00	0.115	8.33	0.000	3.02

TABLE 4-8-D SAVO ISLAND--SUMMARY OF CONTINUOUS FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	DOF
A (U.S.)	1	1	1,2	16	1
	2	7	1,2	37	2
B (JAPAN)	1	1	3	5	2
	2	1	1	10	5
	3	1	7	37	1

TABLE 4-8-E SAVO ISLAND--SUMMARY OF PULSE FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	TUI	TP	E
B (JAPAN)	1	1,2	3	1	5	1	34.01
	2	1,2	1	10	7	1	32.01
	3	1,2	1	18	7	1	48.02

d. Computation of Theoretical Combat Power Loss Intervals

VINCENNES, ASTORIA, QUINCY, CANBERRA and RALPH TALBOT were all lost as a result of the battle while CHICAGO suffered a firepower kill and PATTERSON was damaged. The resulting FC loss interval is 38.89%-43.60% and the resulting FP loss interval is 10.49%-21.18%. The Japanese cruisers KINUGASA and CHOKAI were damaged resulting in an FC loss interval of 0.00%-39.47% and an FP loss interval of 0.00%-37.31%.

e. Comparison of Model Results with the Loss Intervals and Conclusions

The results of the comparison are summarized in Table 4-8-F.

TABLE 4-8-F SAVO ISLAND--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LCL	% FC LOST	UCL	LPL	% FP LOST	UPL
A (U.S.)	38.89	39.77	43.60	10.49	12.28	21.18
B (JAPAN)	0.00	0.16	39.47	0.00	0.16	37.31

Since none of the model's values fall outside of the intervals, there is no reason to question them.

8. Battle of the Eastern Solomons--24 August 1942

The primary sources for data on this battle were Morison [Ref. 15] and Dull [Ref. 14].

a. Force Disposition

Table 4-9-A summarizes the disposition of the forces in the battle.

TABLE 4-9-A FORCES INVOLVED IN THE BATTLE OF THE EASTERN SOLOMONS

FORCE	GROUP	PLATFORMS
A (U.S.)	1	ENTERPRISE, HORNET
B (JAPAN)	1	RYUHO
	2	SHOKAKU, ZUIKAKU

b. Significant Events

Table 4-9-B summarizes the battle's significant events.

TABLE 4-9-B SIGNIFICANT EVENTS OF THE BATTLE OF THE EASTERN SOLOMONS

TIME	EVENT
0905	U.S. land based aircraft locate RYUHO.

1229	ENTERPRISE launches 16 Dauntless scouts (1-500 lb. HC bomb each) and 7 Avengers (1-22.4" torpedo each) to search for the Japanese carriers.
1345	Based only on sketchy information, U.S. carriers launch 30 Dauntlesses (1-1000 lb. HC bomb each) and 8 Avengers (1-22.4" torpedo each) against RYUHO.
1405	Japanese float planes locate U.S. carriers.
1410	ENTERPRISE aircraft locate RYUHO.
1420	ENTERPRISE aircraft locate SHOKAKU and ZUIKAKU.
1507	Japanese carriers launch a strike of 27 Vals (1-250 kg. SAP bombs each).
1550	U.S. strike force attacks RYUHO. Japanese carrier struck by 1-22.4" torpedo and 1-1000 lb. bomb.
1641	Japanese strike attacks ENTERPRISE. The carrier is struck by 3-250 kg. bombs.

c. Computation of Input Parameters

ENTERPRISE and HORNET launched 30 Dauntlesses and scored 1-1000 lb. bomb hit resulting in an estimated PP for this weapon of 0.033. Additionally, the two U.S. carriers launched 8 Avengers and scored 1-22.4" torpedo hit resulting in an estimated PP for this weapon of 0.125. SHOKAKU and ZUIKAKU launched 27 VALS and scored 3-250 kg. bomb hits resulting in an estimated PP of 0.111.

Model input parameters are summarized in Tables 4-9-C and 4-9-D. For the U.S. force, pulse weapon type one (FP1, PP1) is the 500 lb. HC bomb, pulse weapon type two (FP2,

PP2) is the 1000 lb. HC bomb and pulse weapon type three (FP3, PP3) is the 22.4" torpedo. For the Japanese force, pulse weapon type one (FP1, PP1) is the 18" torpedo and pulse weapon type two (FP2, PP2) is the 250 kg. SAP bomb.

TABLE 4-9-C EASTERN SOLOMONS--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FP1	PP1	FP2	PP2	FP3	PP3	SP
A (U.S.)	1	16.77	0.000	36.00	0.033	22.75	0.125	4.54
B (JAPAN)	1	19.55	0.000					1.80
	2	33.52	0.000	8.86	0.111			4.48

TABLE 4-9-D EASTERN SOLOMONS--SUMMARY OF PULSE FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	TUI	TP	E
A (U.S)	1	1	1	45	125	2	30.00
	2	1	1	45	125	3	6.07
B (JAPAN)	1	2	1	127	94	2	5.84

d. Computation of Theoretical Combat Power Loss Intervals

ENTERPRISE was damaged resulting in an FP loss interval for the U.S. force of 0.00%-50.00%. RYUHO was lost resulting in an FP loss value for the Japanese force of 30.48%.

e. Comparison of Model Results with the Loss Intervals and Conclusions

The results of the comparison are summarized in Table 4-9-E.

TABLE 4-9-E EASTERN SOLOMONS--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LCL	% FC LOST	UCL
A (U.S.)	0.00	14.28	50.00
B (JAPAN)	30.48	30.67	30.48

The discrepancy between the model's result and the FP loss value for the Japanese force is accounted for by the same problem discovered in the analysis of the Battle of Midway. As discussed in the Midway analysis, this discrepancy is not considered to be a serious problem since the value produced by the model and the computed loss value both represent the loss of RYUHO.

9. Battle of the Santa Cruz Islands--26 October 1942

The primary sources for data on this battle were Morison [Ref. 15] and Dull [Ref. 14].

a. Force Disposition

Table 4-10-A summarizes the disposition of the forces in the battle.

TABLE 4-10-A FORCES INVOLVED IN THE BATTLE OF SANTA CRUZ ISLANDS

FORCE	GROUP	PLATFORMS
A (JAPANESE)	1	SHOKAKU
	2	ZUIKAKU
	3	ZUIHO
	4	JUNYO
B (U.S.)	1	ENTERPRISE
	2	HORNET

b. Significant Events

Table 4-10-B summarizes the battle's significant events.

TABLE 4-10-B SIGNIFICANT EVENTS OF THE BATTLE OF SANTA CRUZ ISLANDS

TIME	EVENT
0500	U.S. carriers launch 16 Dauntless scouts (1-500 lb. HC bomb each).
0650	Two other U.S. search aircraft locate the main Japanese carrier force.
0730-0815	U.S. carriers launch a strike consisting of 27 Dauntlesses (1-1000 lb. HC bomb each) and 23 Avengers (1-22.4" torpedo each).
0740	ENTERPRISE Dauntless scouts attack ZUIHO scoring two bomb hits.
0758	Japanese carriers launch a strike consisting of 22 Vals (1-250 kg. SAP bomb each) and 18 Kates (1-18" torpedo each).
0830	Japanese carriers launch a second strike consisting of 20 Vals and 18 Kates.
0845	JUNYO launches a strike consisting of 20 Vals (1-250 kg. SAP bomb each).
0910	First of the Japanese main strikes attacks HORNET scoring five bomb hits and two torpedo hits.
0930	U.S. air strike attacks the Japanese carriers. SHOKAKU hit by four bombs.
1005	Second of the Japanese main strikes attacks ENTERPRISE scoring two bomb hits.
1122	JUNYO's 20 Vals attack ENTERPRISE, no hits.

1400 JUNYO launches a second strike consisting of five Vals (1-250 kg. SAP bomb each) and six Kates (1-18" torpedo each).

1623 JUNYO's second strike attacks HORNET scoring 1-18" torpedo hit.

c. Computation of Input Parameters

SHOKAKU and ZUIKAKU launched 42 Vals and scored 7-250 kg. bomb hits, resulting in an estimated PP of 0.167. Additionally, SHOKAKU, ZUIKAKU and ZUIHO launched 30 Kates and scored 2-18" torpedo hits, resulting in an estimated PP for this weapon of 0.067. JUNYO launched six Kates and scored 1-18" torpedo hit , resulting in an estimated PP of 0.167. The two U.S. carriers launched 27 Dauntlesses and scored 4-1000 lb. bomb hits, resulting in an estimated PP for this weapon of 0.148.

Model input parameters are summarized in Tables 4-10-C and 4-10-D. For the Japanese force, pulse weapon type one (FP1, PP1) is the 250 kg. SAP bomb and pulse weapon type two (FP2, PP2) is the 18" torpedo. For the U.S. force, pulse weapon type one (FP1, PP1) is the 500 lb. HC bomb, pulse weapon type two (FP2, PP2) is the 1000 lb HC bomb and pulse weapon type three (FP3, PP3) is the 22.4" torpedo.

TABLE 4-10-C SANTA CRUZ ISLANDS--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FP1	PP1	FP2	PP2	FP3	PP3	SP
A (JAPAN)	1	4.32	0.167	21.41	0.067		0.000	2.24
	2	5.84	0.167	16.76	0.067		0.000	2.24
	3			5.59	0.167		0.000	1.70
	4	4.54	0.000	9.31	0.167		0.000	2.14
B (U.S.)	1	8.38	0.125	18.00	0.148	9.10	0.000	2.42
	2	8.38	0.125	18.00	0.148	11.38	0.000	2.07

TABLE 4-10-D SANTA CRUZ ISLANDS--SUMMARY OF PULSE FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	TUI	TP	E
A (JAPAN)	1	1,2	2	179	72	1	4.76
	2	1,2,3	2	179	72	2	16.76
	3	1,2	1	211	95	1	4.32
	4	1,2,3	1	211	95	2	11.17
	5	4	2	541	143	2	5.59
B (U.S.)	1	1,2	3	1	160	1	7.45
	2	1,2	1,3	151	120	2	27.00

d. Computation of Theoretical Combat Power Loss Intervals

SHOKAKU suffered a firepower kill in this battle resulting in an FP loss value for the Japanese force of 45.36%. HORNET was lost and ENTERPRISE was damaged resulting in an FP loss interval for the U.S. force of 51.32% -100.00%.

e. Comparisons of Model Results with the Loss Intervals and Conclusions

The results of the comparison are summarized in Table 4-10-E.

TABLE 4-10-E SANTA CRUZ ISLANDS--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LPL	% FP LOST	UPL
A (JAPAN)	45.36	46.22	45.36
B (U.S.)	51.32	61.67	100.00

The discrepancy between the model's result and the FP loss value for the Japanese is accounted for by the same problem discovered in the analyses of the Battle of Midway and the Battle of the Eastern Solomons. As discussed in these other analyses, this discrepancy is not considered to be a serious problem since the value produced by the model and the computed loss value both represent the loss of SHOKAKU.

10. Naval Battle of Guadalcanal (Second Night)--14/15 November 1942.

The primary sources for data on this battle were Morison [Ref. 15] and Dull [Ref. 14].

a. Force Disposition

Table 4-11-A summarizes the disposition of forces in the battle.

TABLE 4-11-A FORCES INVOLVED IN THE NAVAL BATTLE OF GUADALCANAL (SECOND NIGHT)

FORCE	GROUP	PLATFORMS
A (U.S.)	1	SOUTH DAKOTA
	2	WASHINGTON
	3	WALKE, BENHAM, PRESTON, GWIN
B (JAPANESE)	1	SENDAI
	2	SHIKINAMI, URANAMI, AYANAMI
	3	NAGARA
	4	ASAGUMO, TERUZUKI, INAZUMA, SHIRAYUKI
	5	KIRISHIMA
	6	ATAGO, TAKAO
	7	HATSUYUKI, SAMIDARE

b. Significant Events

Table 4-11-B summarizes the battle's significant events.

TABLE 4-11-B SIGNIFICANT EVENTS OF THE NAVAL BATTLE OF GUADALCANAL (SECOND NIGHT)

TIME	EVENT
2322	U.S. destroyers exchange fire with AYANAMI and URANAMI.
2330	AYANAMI and URANAMI fire 18-24" torpedoes.
2335	NAGARA, ASAGUMO, TERUZUKI, INAZUMA, and SHIRAYUKI fire 34-24" torpedoes.
	WALKE fires 8-21" torpedoes.
	WALKE and PRESTON, badly damaged, fall out of the engagement.
2337	GWIN fires on NAGARA which, with four destroyers, returns fire. GWIN is badly damaged and is forced to withdraw minutes later.
2338	WALKE and BENHAM each hit by one torpedo.

2355	NAGARA and her four destroyers launch 34 more torpedoes.
	NAGARA, ATAGO, TAKAO and KIRISHIMA open fire on SOUTH DAKOTA. SOUTH DAKOTA returns fire.
0005	WASHINGTON enters the engagement, firing primarily on KIRISHIMA.
0010	SOUTH DAKOTA falls out of the engagement.
	Battle is essentially over. Japanese withdraw by 0025.

c. Computation of Input Parameters

(1) Number of Shells Fired. WASHINGTON fired both her 16" battery and 5" battery (on one side) for eight minutes. The number of 16" shells fired was given by Morison [Ref. 15] to be 75 while the number of 5" shells was estimated to be 1400 for a total estimate of 1475 shells fired. NAGARA fired for a total of 20 minutes resulting in an estimate of 840 shells fired. KIRISHIMA fired for 18 minutes, resulting in an estimate of 252 shells fired. ATAGO and TAKAO also fired for 18 minutes, resulting in an estimate of 1440 shells fired by both platforms.

(2) Weapon Effectiveness. WASHINGTON scored 49 hits, resulting in an overall estimate of this ship's PC of 0.033. NAGARA scored five hits, resulting in an estimated PC of 0.006. KIRISHIMA scored one hit, resulting in an estimated PC of 0.004. ATAGO and TAKAO scored 18 hits resulting in an estimated PC of 0.013. Finally, SHIKINAMI, URANAMI and AYANAMI together fired 18-24" torpedoes and scored two hits,

resulting in an estimated PP for these platforms of 0.11. No other platforms fired with effect in this battle.

Input parameters are summarized in Tables 4-11-C, 4-11-D, and 4-11-E. For the U.S. force, pulse weapon type one (FP1, PP1) is the 21" torpedo. For the Japanese force, pulse weapon type one (FP1, PP1) is the 24" "Long Lance" torpedo.

d. Computation of Theoretical Combat Power Loss Intervals

SOUTH DAKOTA suffered a firepower kill and the four U.S. destroyers were lost, resulting in an FC loss value for the U.S. force of 61.69% and an FP loss value of 100.00%. KIRISHIMA was lost and ATAGO and TAKAO were damaged, resulting in an FC loss interval for the Japanese Force of 25.99%-57.05% and an FP loss interval of 0.00%-15.69%.

TABLE 4-11-C NAVAL BATTLE OF GUADALCANAL (SECOND NIGHT)--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FC	PC	FP1	PP1	SP
A (U.S.)	1	16.20	0.000			2.49
	2	16.20	0.033			2.49
	3	9.89	0.000	52.89	0.000	3.69
B (JAPAN)	1	1.34	0.000	16.01	0.000	1.35
	2	2.15	0.000	54.02	0.110	2.83
	3	1.34	0.006	8.00	0.000	1.25
	4	3.61	0.000	60.03	0.000	3.89
	5	5.83	0.004			2.23
	6	6.97	0.013	32.01	0.000	3.44
	7	1.19	0.000	34.01	0.000	1.84

TABLE 4-11-D NAVAL BATTLE OF GUADALCANAL (SECOND NIGHT)--SUMMARY OF CONTINUOUS FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	DOF
A (U.S.)	1	2	5,6	49	8
B (JAPAN)	1	3	3	21	2
	2	3,5,6	1	39	18

TABLE 4-11-E NAVAL BATTLE OF GUADALCANAL (SECOND NIGHT)--SUMMARY OF PULSE FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	TUI	TP	E
B (JAPAN)	1	2	3	14	8	1	36.02

e. Comparison of Model Results with the Loss Intervals and Conclusions

The results of the comparison are summarized in Table 4-11-F.

TABLE 4-11-F NAVAL BATTLE OF GUADALCANAL (SECOND NIGHT)--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LCL	% FC LOST	UCL	LPL	% FP LOST	UPL
A (U.S.)	61.69	51.71	61.69	100.00	100.00	100.00
B (JAPAN)	25.99	43.04	57.05	0.00	11.83	15.69

As can be seen from the table, a major discrepancy exists between the model's percent FC loss result for the U.S. force and the computed FC loss value. Investigation revealed

that the discrepancy was caused by the fact that SOUTH DAKOTA was knocked out of the battle with fewer TPBE hits than predicted by the survivability model (Appendix A). As in the case of the River Plate analysis above, this result does not suggest a major weakness in the model. Instead, it points to the fact that the model does not address the detailed issues which make each platform peculiar unto itself and cause anomalies such as the early firepower kill of SOUTH DAKOTA in this battle.

11. Battle of Tassafaronga--30 November 1942

The primary sources for data on this battle were Morison [Ref. 17] and Dull [Ref. 14].

a. Force Disposition

Table 4-12-A summarizes the disposition of forces in the battle.

TABLE 4-12-A FORCES INVOLVED IN THE BATTLE OF TASSAFARONGA

FORCE	GROUP	PLATFORMS
A (U.S.)	1	MINNEAPOLIS, NEW ORLEANS, PENSACOLA, NORTHAMPTON
	2	HONOLULU
	3	FLETCHER, DRAYTON, MAURY, PERKINS, LAMSON, LARDNER
B (JAPAN)	1	TAKANAMI
	2	NAGANAMI, MAKINAMI, KUROSHIO, OYASHIO, KAGERO, KAWAKAZE, SUZUKAZE

b. Significant Events

Table 4-12-B summarizes the battle's significant events.

TABLE 4-12-B SIGNIFICANT EVENTS OF THE BATTLE OF TASSAFARONGA

TIME	EVENT
2321	U.S. destroyers launch an ineffective torpedo attack.
	U.S. cruisers open fire on TAKINAMI.
	TAKINAMI fires 8-24" torpedoes.
2327	MINNEAPOLIS struck by two of TAKINAMI's torpedoes, NEW ORLEANS hit by one.
2328	KUROSHIO and OYASHIO fire 12-24" torpedoes.
2330	KAWAKAZE, KUROSHIO and NAGANAMI fire 20-24" torpedoes.
2339	PENSACOLA struck by one torpedo.
2348	NORTHAMPTON struck by two torpedoes.

c. Computation of Input Parameters

(1) Duration of Continuous Fire. *The U.S.* 8" gun cruisers fired 363 shells resulting in an estimated duration of fire of three minutes. Morison's account [Ref. 17] portrays HONOLULU as firing her 6" guns during the same period as the 8" cruisers so her duration of fire was also estimated as three minutes.

(2) Weapon Effectiveness. No data was available on the number of U.S. shells which struck their targets. The PC of the U.S. cruisers was, therefore, estimated to be 0.037, the estimated PC of the U.S. cruisers at Savo Island. TAKINAMI fired 8-24" torpedoes and scored three hits, resulting in an estimated PP of 0.375. The remaining Japanese ships fired 32-24" torpedoes and also scored three hits,

resulting in an estimated PP of 0.094. No other ships fired with effect in this battle.

Tables 4-12-C, 4-12-D and 4-12-E summarize the model input parameters. For the U.S. force, pulse weapon type one (FP1, PP1) is the 21" torpedo. For the Japanese force, pulse weapon type one (FP1, PP1) is the 24" "Long Lance" torpedo.

TABLE 4-12-C TASSAFARONGA--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FC	IC	FP1	PP1	SP
A (U.S.)	1	12.37	0.037			6.43
	2	7.54	0.037			1.62
	3	15.10	0.000	81.03	0.000	5.57
B (JAPAN)	1	0.48	0.000	16.01	0.375	0.96
	2	3.34	0.000	112.05	0.094	6.57

TABLE 4-12-D TASSAFARONGA--SUMMARY OF CONTINUOUS FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	DOF
A (U.S.)	1	1,2	1	1	3

TABLE 4-12-E TASSAFARONGA--SUMMARY OF PULSE FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	TUI	TP	E
B (JAPAN)	1	1	1	1	6	1	16.01
	2	2	1	7	11	1	24.01
	3	2	1	10	17	1	40.01

d. Computation of Theoretical Combat Power Loss Intervals

All four U.S. 8" gun cruisers suffered a firepower kill, resulting in an FC loss value of 35.35% and an FP loss value of 0.00%. TAKINAMI was lost in the engagement, resulting in an FC loss value of 12.50% and an FP loss value of 12.50%.

e. Comparison of Model Results with the Loss Intervals and Conclusions.

The results of the comparison are summarized in Table 4-12-F.

TABLE 4-12-F TASSAFARONGA--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LCL	% FC LOST	UCL	LPL	% FP LOST	UPL
A (U.S.)	35.35	35.35	35.35	0.00	0.00	0.00
B (JAPAN)	12.50	12.50	12.50	12.50	12.50	12.50

Since the model's results match the computed values, there is no reason to question them.

12. Battle of Komandorski Island--25 March 1943

The primary sources for data on this battle were Morison [Ref. 18] and Dull [Ref. 14].

a. Force Disposition

Table 4-13-A summarizes the disposition of the forces in the battle.

TABLE 4-13-A FORCES INVOLVED IN THE BATTLE OF KOMANDORSKI ISLAND

FORCE	GROUP	PLATFORMS
A (U.S.)	1	SALT LAKE CITY
	2	RICHMOND
	3	BAILEY, COGHLAN
	4	DALE, MONAGHAN
B (JAPAN)	1	NACHI, MAYA
	2	ABUKUMA, TAMA, AKABA, HATSUSHIMO

b. Significant Events

Table 4-13-B summarizes the battle's significant events.

TABLE 4-13-B SIGNIFICANT EVENTS OF THE BATTLE OF KOMANDORSKI ISLANDS

TIME	EVENT
0842	NACHI and MAYA open fire on SALT LAKE CITY.
	SALT LAKE CITY returns fire.
	NACHI ceases fire for approximately 30 minutes.
0915	NACHI resumes fire. NACHI, MAYA and SALT LAKE CITY exchange fire intermittently for several hours.
1150	SALT LAKE CITY ceases fire.
	U.S. destroyers close Japanese line in an attempt to divert fire from badly damaged SALT LAKE CITY.
1200	SALT LAKE CITY resumes fire.
1210	Japanese break off the engagement.

c. **Computation of Input Parameters**

(1) Duration of Continuous Fire. SALT LAKE CITY fired 323-8" shells, resulting in an estimated duration of fire of 21 minutes. BAILEY and COGHLAN together fired 2314-5" shells, resulting in an estimated duration of fire of seven minutes. NACHI and MAYA together fired 1611-8" shells, resulting in an estimated duration of fire of 20 minutes.

(2) Weapon Effectiveness. SALT LAKE CITY scored three hits, resulting in an estimated PC of 0.004. BAILEY and COGHLAN scored one hit, resulting in an estimated PC of 0.0004. NACHI and MAYA scored six hits, resulting in an estimated PC of 0.004.

The model's input parameters are summarized in Tables 4-13-C and 4-13-D. For the U.S. force, pulse weapon type one (FP1, PP1) is the 21" torpedo with TORPEX warhead. For the Japanese force, pulse weapon type one (FP1, PP1) is the 24" "Long Lance" torpedo.

TABLE 4-13-C KOMANDORSKI ISLANDS--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FC	PC	FP1	PP1	SP
A (U.S.)	1	3.34	0.004			1.59
	2	6.03	0.000	7.01	0.000	1.35
	3	5.21	0.0004	46.75	0.000	1.88
	4	5.21	0.0004	37.40	0.000	1.80
B (JAPAN)	1	6.97	0.004	24.01	0.000	3.45
	2	3.65	0.000	40.02	0.000	4.21

TABLE 4-13-D KOMANDORSKI ISLANDS--SUMMARY OF CONTINUOUS FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	DOF
A (U.S.)	1	1	1	1	21
	2	3,4	1,2	21	7
B (JAPAN)	1	1	1	1	19
	2	1	3	21	1

d. Computation of Theoretical Combat Power Loss Intervals

SALT LAKE CITY and BAILEY were damaged resulting in an FC loss interval for the U.S. force of 0.00%-30.13% and an FP loss interval of 0.00%-25.64%. MAYA was damaged resulting in an FC loss interval for the Japanese force of 0.00% - 32.84% and an FP loss interval of 0.00% -12.50%.

e. Comparison of Model Results with the Loss Intervals and Conclusions

The results of the comparison are summarized in Table 4-13-E.

TABLE 4-13-E KOMANDORSKI ISLANDS--COMPARISON OF MODEL RESULTS WITH THEORETICAL COMBAT POWER LOSS INTERVALS

FORCE	LCL	% FC LOST	UCL	LPL	% FP LOST	UPL
A (U.S.)	0.00	5.81	30.13	0.00	0.71	25.64
B (JAPAN)	0.00	4.80	32.84	0.00	2.91	12.50

Since none of the model's results fall outside the intervals, there is no reason to question them.

13. Battle of Kula Gulf--06 July 1943

Morison [Ref. 17] and Dull [Ref. 14] were the primary sources of data on this battle.

a. Force Disposition

Table 4-14-A summarizes the disposition of the forces in the battle.

TABLE 4-14-A FORCES INVOLVED IN THE BATTLE OF KULA GULF

FORCE	GROUP	PLATFORMS
A (U.S.)	1	HELENA
	2	HONOLULU, ST. LOUIS
	3	O'BANNON, NICHOLAS, RADFORD, JENKINS
B (JAPAN)	1	NIITSUKI
	2	SUZUKAZI, TANIKAZI
	3	AMAGIRI, HATSUYUKI, NAGATSUKI, SATSUKI

b. Significant Events

Table 4-14-B summarizes the battle's significant events.

TABLE 4-14-B SIGNIFICANT EVENTS OF THE BATTLE OF KULA GULF

TIME	EVENT
0140	U.S. force detects Japanese force.
0157	U.S. cruisers open fire on NIITSUKI.
	SUZUKAZI and TANIKAZI fire 16-24" torpedoes.
0201	U.S. cruisers shift fire to SUZUKAZI and TANIKAZI.
0203	U.S. column reverses course and ceases firing.
	HELENA hit by 1-24" torpedo.

0203-0220	U.S. destroyers fire several ineffective torpedo salvoes.
0218	U.S. cruisers open fire on AMAGIRI, HATSUYUKI, NAGATSUKI and SATSUKI. Firing is highly intermittent.
0235	U.S. force ceases fire and breaks off the engagement.

c. Computation of Input Parameters

(1) Duration of Continuous Fire. The U.S. cruisers fired 2500-6" shells, resulting in an estimated duration of fire of six minutes.

(2) Weapon Effectiveness. The U.S. cruisers scored 28 hits resulting in an estimated PC of 0.011. SUZUKAZI and TANIKAZI fired 16-24" torpedoes and scored three hits, resulting in an estimated PP of 0.188. No other platforms fired with any effect in the battle.

All input parameters are summarized in Tables 4-14-C, 4-14-D and 4-14-E. For the U.S. force, pulse weapon type one (FP1, PP1) is the 21" torpedo with TORPEX warhead. For the Japanese force, pulse weapon type one (FP1, PP1) is the 24" "Long Lance" torpedo.

TABLE 4-14-C KULA GULF--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FC	PC	FP1	PP1	SP
A (U.S.)	1	7.54	0.011			1.62
	2	15.08	0.011			3.24
	3	10.41	0.000	93.50	0.000	4.04
B (JAPAN)	1	1.70	0.000	8.00	0.000	1.09
	2	0.96	0.000	32.01	0.188	1.85
	3	1.95	0.000	60.03	0.000	3.62

TABLE 4-14-D KULA GULF--SUMMARY OF CONTINUOUS FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	DOF
A (U.S.)	1	1,2	1	17	4
	2	1,2	2	21	1
	3	2	3	38	1

TABLE 4-14-E KULA GULF--SUMMARY OF PULSE FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	TUI	E
B (JAPAN)	1	2	1	17	6	32.01

d. Computation of Theoretical Combat Power Loss Intervals.

HELENA suffered a firepower kill in this battle, resulting in an FC loss value for the U.S. force of 22.83% and an FP loss value of 0.00%. NIITSUKI was lost in this battle while SUZUKAZI and TANIKAZI were damaged, resulting in an FC loss interval for the Japanese force of 36.93% - 57.65% and an FP loss interval of 8.00%-42.00%.

e. Comparison of Model Results with Loss Intervals and Conclusions

The results of the comparison are summarized in Table 4-14-F.

TABLE 4-14-F KULA GULF--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LCL	% FC LOST	UCL	LPL	% FP LOST	UPL
A (U.S.)	22.83	22.83	22.83	0.00	0.00	0.00
B (JAPAN)	36.93	39.11	57.65	8.00	14.62	42.00

Since none of the model's values fall outside the computed intervals, there is no reason to question them.

14. Battle of Vella Gulf--6/7 August 1943

Morison [Ref. 17] and Dull [Ref. 14] were the primary sources of data on this battle.

a. Force Disposition.

Table 4-15-A summarizes the disposition of Forces in the battle.

TABLE 4-15-A FORCES INVOLVED IN THE BATTLE OF VELLA GULF

FORCE	GROUP	PLATFORMS
A (U.S.)	1	DUNLAP, CRAVEN, MAURY
	2	LONG, STERETT, STACK
B (JAPAN)	1	KAWAKAZE, ARASHI, HAGIKAZE
	2	SHIGURE

b. Significant Events

Table 4-15-B summarizes the battle's significant events.

TABLE 4-15-B SIGNIFICANT EVENTS OF THE BATTLE OF VELLA GULF

TIME	EVENT
2333	U.S. force detects Japanese force.
2341	DUNLAP, CRAVEN, and MAURY fire 24-21" torpedoes.
2345	HAGIKAZE is hit by two torpedoes ARASHI by three torpedoes and KAWAKAZE by one.
2345	LONG, STERETT and STACK open fire with 5" guns. Japanese ships return fire ineffectively.
	STACK fires four torpedoes.
2355	DUNLAP, CRAVEN and MAURY open fire on ARASHI and KAWAKAZE.
0010	ARASHI blows up.
0018	KAWAKAZE blows up.
	SHIGURE withdraws.

c. Computation of Input Parameters

(1) Number of Shells Fired. DUNLAP, CRAVEN and MAURY fired for 27 minutes, resulting in an estimate of 6143-5" shells fired. LONG, STERETT and STACK fired for a total of 34 minutes, resulting in an estimate of 7140-5" shells fired.

(2) Weapon Effectiveness. No data was available on the number of U.S. shells which hit their targets. The PC of both groups is, therefore, assumed to be 0.011, the PC of the U.S. ships at Kula Gulf. DUNLAP, CRAVEN and MAURY fired 24-21" torpedoes and scored six hits, resulting in an estimated PP of 0.250. No other platforms fired with effect in this battle.

All input parameters are summarized in Tables 4-15-C, 4-15-D and 4-15-E. For the U. S. force, pulse weapon type one (FP1, PP1) is the 21" torpedo with TORPEX warhead. For the Japanese force, pulse weapon type one (FP1, PP1) is the 24" "Long Lance" torpedo.

TABLE 4-15-C VELLA GULF--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FC	PC	FP1	PP1	SP
A (U.S.)	1	6.77	0.011	56.10	0.250	2.74
	2	6.25	0.011	56.10	0.000	2.76
B (JAPAN)	1	1.43	0.000	48.02	0.000	2.80
	2	0.48	0.000	16.01	0.000	0.90

TABLE 4-15-D VELLA GULF--SUMMARY OF CONTINUOUS FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	DOF
A (U.S.)	1	2	1	5	34
	2	1	1	12	27

TABLE 4-15-E VELLA GULF--SUMMARY OF PULSE FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	TUI	TP	E
A (U.S.)	1	1	1	1	4	1	56.10

d. Computation of Theoretical Combat Power Loss Intervals

The Japanese force lost KAWAKAZE, ARASHI, and HAGIKAZE resulting in FC and FP loss values equal to 75.00%. U.S. platforms suffered no damage in this battle.

e. Comparison of Model Results with the Loss Values and Conclusions

The results of the comparison are summarized in Table 4-15-F.

TABLE 4-15-F VELLA GULF--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LCL	% FC LOST	UCL	LPL	% FP LOST	UPL
A (U.S.)	0.00	0.00	0.00	0.00	0.00	0.00
B (JAPAN)	75.00	75.00	75.00	75.00	75.00	75.00

Since the model's results match the computed values, there's no reason to question them.

F. VALIDATION'S VALUE IN FINE TUNING THE MODEL

In the model's original design, platforms of each force were not organized into component groups but were aggregated together into one group representing the entire force. Each force was represented by single values of SP, FC, and FP.

Within the context of the model, therefore, each force fired as a single unit, unleashing all of its FC and/or FP on its opponent. in addition, effective combat power inflicted by a force was distributed evenly across all platforms of the opposing force. Testing this early form of the model using historical data pointed out a serious weakness in the model's assumptions requiring modification into its present form.

The battle which was used to test the model in its early form was the Battle of Savo Island. Model input parameters are summarized in tables 4-16-A, 4-16-B and 4-16-C.

TABLE 4-16-A SAVO ISLAND (FULLY AGGREGATED MODEL)--STAYING POWER, THEORETICAL COMBAT POWER AND WEAPON EFFECTIVENESS VALUES

FORCE	GROUP	FC	PC	FP1	PP1	FP2	PP2	SP
A (U.S.)	1	27.11	0.037	112.19	0.000	5.51	0.000	18.50
B (JAPAN)	1	11.85	0.090	56.02	0.115			10.90

TABLE 4-16-B SAVO ISLAND (FULLY AGGREGATED MODEL)--SUMMARY OF CONTINUOUS FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	DOF
A (U.S.)	1	1	1	16	1
	2	1	1	37	2
B (JAPAN)	1	1	1	5	2
	2	1	1	10	5
	3	1	1	37	1

TABLE 4-16-C SAVO ISLAND (FULLY AGGREGATED MODEL)--SUMMARY OF PULSE FIRE ENGAGEMENTS

FORCE	EVENT	GF	GBA	TOF	TUI	TP	E
B (JAPAN)	1	1	1	1	5	1	34.01
	2	1	1	10	7	1	32.01
	3	1	1	18	7	1	48.02

As can be seen from the tables, the FP and SP values are simply the sums of the values found in Table 4-8-C. FC, however, was computed based only on the 8" gun cruisers' individual FC values since it was the cruisers which fired with the most effect in the battle. PC for both forces was estimated from the ratio of the number of 8" shells which hit their targets to the number fired. Torpedo PP was estimated as described in the Savo Island analysis above. Times and duration of continuous and pulse fire were also left unchanged. Table 4-16-D summarizes the comparison of model results with the theoretical combat power loss intervals.

TABLE 4-16-D SAVO ISLAND (FULLY AGGREGATED MODEL)--COMPARISON OF MODEL RESULTS WITH LOSS INTERVALS

FORCE	LCL	% FC LOST	UCL	LPL	% FP LOST	UPL
A (U.S.)	38.89	100.00	43.60	10.49	100.00	21.18
B (JAPAN)	0.00	3.54	39.47	0.00	3.54	37.31

As can be seen in the table, glaring discrepancies exist between the computed FC and FP loss intervals and the model's percent FC and FP loss results for the U.S. force.

Investigation revealed that these discrepancies stemmed from the fact that the model was distributing Japanese fire (and the consequent attrition) over the entire U.S. force. Japanese fire in the actual battle, however, was focused primarily on the Northern and Southern Force cruisers. The model, therefore, produced results which reflected much higher losses than were actually sustained by the U.S. force.

The solution to this problem was to enhance the model by allowing the user to segregate the battle into separate engagements of component groups. The user was now able to regulate and focus each group's fire. As can be seen from the analysis of Savo Island conducted with the enhanced model, a much better result was produced.

It is obvious that the current, enhanced model allows the user much greater flexibility in exploring his tactical options and is a much more realistic portrayal of naval combat. This, however, was not intuitively obvious at the outset. It required analysis, using actual battle data, to discover the problem and correct it. The conclusion, therefore, is that historical battle data is an extremely useful tool in the process of model enhancement and validation.

G. CONCLUSIONS

Concerning the issue of model validation, Hughes [Ref. 19] has stated the following:

> We see then why the analyst is disconcerted when asked whether he has validated his model. The answer must always be no. The correct questions are: what steps has he taken to corroborate his model and over what range of application can it be shown to be utilitarian.

This chapter has sought to answer the first of these questions. Of the 40 theoretical combat power loss percentages produced by model runs incorporating data from 14 naval battles only two deviated significantly from their corresponding combat power loss intervals. Investigation revealed that these deviations were caused by anomalies peculiar to a particular platform and not to a fundamental model weakness. The conclusion, therefore, is that the model's results have been corroborated to be a fair representation of reality.

The next chapter will address the second question by demonstrating the model's potential for application as a tactical planning tool.

V. APPLICATION OF THE MODEL AS A TACTICAL PLANNING TOOL

A. INTRODUCTION

For any battle model to be useful as a tactical decision aid, it must be simple, credible and applicable to the battle situations for which the user is developing his tactics. That this model is simple and credible has already been demonstrated. This chapter will explore the model's potential for application as a modern tactical planning tool by using it to evaluate the U.S. commander's tactical options at the Battle of Savo Island, a battle which has much in common with modern naval battle scenarios.

B. TACTICAL ANALYSIS OF THE BATTLE OF SAVO ISLAND

1. Composition of the Opposing Forces

Table 5-1 summarizes the staying power and combat power of the U.S. and Japanese forces at Savo Island.

As is evident from the table, the U.S. force was overwhelmingly superior in both staying power and combat power to the Japanese force. Flaws in the U.S. commander's tactical plan, however, greatly undermined this superiority and gave the Japanese commander a more than even chance for victory.

TABLE 5-1 BREAKDOWN OF FORCES IN THE BATTLE OF SAVO ISLAND

FORCE	SP	FC	FP
U.S.			
Northern Group			
3 CA's	4.89	9.03	0.00
2 DD's	1.84	4.17	24.93
Southern Group			
2 CA's	3.31	6.38	0.00
2 DD's	1.84	4.17	24.93
Eastern Group			
2 CL's	2.90	11.70	11.74
2 DD's	1.88	5.21	31.17
Pickets			
2 DD's	1.84	4.17	24.93
TOTAL	18.50	44.83	117.70
JAPANESE			
5 CA's	7.88	11.85	48.02
2 CL's	2.18	1.92	13.00
1 DD	0.84	0.36	3.33
TOTAL	10.90	14.13	64.35

2. Tactics of the Opposing Forces

a. U.S. Tactics

The mission of the U.S. force was to protect the American beachhead on Guadalcanal. To accomplish this, the U.S. commander organized his force into three groups (Table 5-1), each tasked with protecting a direction of approach to the American beachhead. The U.S. commander relied on the (perceived) superiority of his platforms' gunnery to handle any surface threat.

b. Japanese Tactics

The mission of the Japanese force was to destroy American supply transports at Guadalcanal, as well as any naval opposition encountered there. To accomplish his mission, the Japanese commander organized his force into a single group in order to initiate his attacks with massed torpedo salvoes. Gunfire would be used to mop up after the torpedo attacks.

3. Course and Outcome of the Battle

The Japanese force approached Guadalcanal from the northwest attacking the U.S. group patrolling south of Savo Island first. The Japanese then turned to the northeast and attacked the group patrolling north of Savo before breaking off the engagement. Both U.S. groups were taken by surprise. The Americans lost four heavy cruisers. One heavy cruiser and one destroyer were heavily damaged. The Japanese suffered only slight damage to two of their heavy cruisers.

The fundamental flaw in the U.S. tactical plan can be seen by evaluating Table 5-1 in light of each opponent's tactics. The U.S. commander's decision to divide his forces left each U.S. group inferior to the Japanese force even though the U.S. force was superior in aggregate. The Japanese commander was able to employ his torpedoes against the northern and southern American groups separately, devastating each in turn. Further, the U.S. groups allowed themselves to be surprised. They were, therefore, unable to inflict any serious damage on the Japanese.

C. USING THE MODEL TO EVALUATE U.S. TACTICAL OPTIONS

1. U.S. Commander's Estimate of Own and Enemy Capabilities

U.S. patrol aircraft had located the Japanese force on the day before the battle and had reported its composition as three heavy cruisers and three destroyers. The U.S. commander could have used the latest edition of Jane's Fighting Ships to determine that the typical Japanese heavy cruiser mounted six 8" guns, could fire four torpedoes in a single salvo, and had a full load displacement of approximately 10,500 tons. A typical Japanese destroyer mounted four 5" guns, could fire eight torpedoes in a single salvo, and had a full load displacement of 2200 tons. Additionally, the U.S. commander might have assumed that the characteristics of Japanese weapons were roughly similar to those of their U.S. counterparts.

Based on his knowledge and assumptions concerning the Japanese force, the U.S. commander could have estimated its FC, FP and SP values as in Table 5-2.

TABLE 5-2 U.S. COMMANDER'S ESTIMATE OF JAPANESE STRENGTH

	SP	FC	FP
3 CA's	4.62	6.02	18.70
3 DD's	2.75	6.25	37.40
TOTAL	7.37	12.27	56.10

The U.S. commander might also have made the following assumptions about his own and his enemy's capabilities:

- U.S. and Japanese PC = 0.03 (a value which is consistent with U.S. Naval War College estimates in the 1930's).
- U.S. torpedo PP = 0.05.
- Japanese torpedo PP = 0.10.

The Japanese torpedo PP was assigned a value twice that of the U.S. under the assumption that the U.S. commander was aware that the Japanese had employed torpedoes to good effect at the Battle of Java Sea some months earlier.

2. Developing Scenarios Which Test U.S. Tactical Options

Having estimated enemy strength and capabilities, the U.S. commander would have used the model to explore his tactical options. In this spirit, four scenarios were developed reflecting these options. In each, the Japanese force is organized into a single group and initiates the engagement with a torpedo attack.

a. Scenario One

The U.S. Commander deploys his force as in the actual battle. The Japanese attack the northern U.S. group first. The southern U.S. group joins the engagement ten minutes later. The eastern U.S. group is too far away to join until after the Japanese escape. None of the U.S. groups employ torpedoes.

b. Scenario Two

This scenario is identical to scenario one except that the U.S. groups employ torpedoes as well as gunfire.

c. Scenario Three

The U.S. commander deploys his forces so as to concentrate his combat power but does not employ torpedoes.

d. Scenario Four

This scenario is identical to scenario three except that the U.S. force employs torpedoes as well as gunfire.

3. Computing Model Input Parameters Reflecting Each Scenario.

Model input parameters were computed representing:

- Actual FC, FP and SP values of the U.S. force (Table 5-1).
- Estimated FC, FP and SP values of the Japanese force (Table 5-2)
- Interaction of the opposing forces in each scenario.

Parameters were computed and run twice for each scenario, once in which the Japanese surprise the U.S. force (S) and once in

Parameters were computed and run twice for each scenario, once in which the Japanese surprise the U.S. force (S) and once in which they fail to achieve surprise (NS). Gunfire did not commence in either force in those scenarios involving Japanese surprise attack until the first Japanese torpedo salvo struck its targets.

4. Model Results for Each Scenario

Table 5-3 summarizes the model's results for each scenario. Each model run would have taken less than one second of computing time on a personal computer.

TABLE 5-3 LOSS PERCENTAGES FOR EACH SCENARIO

	U.S. FORCES			JAPANESE FORCES		
SCENARIO	SP	FC	FP	SP	FC	FP
1(NS)	47.69	39.27	33.86	100.00	100.00	100.00
1(S)	74.16	62.28	63.54	69.09	69.09	69.09
2(NS)	45.04	36.97	30.89	100.00	100.00	100.00
2(S)	62.10	51.80	50.02	100.00	100.00	100.00
3(NS)	36.94	36.94	36.94	100.00	100.00	100.00
3(S)	39.63	39.63	39.63	100.00	100.00	100.00
4(NS)	36.94	36.94	36.94	100.00	100.00	100.00
4(S)	39.63	39.63	39.63	100.00	100.00	100.00

Table 5-3 clearly shows that the U.S. force fares worst in the scenario in which its commander divides his platforms so that they cannot concentrate their combat power, fails to employ his torpedoes, and allows himself to be surprised (scenarios 1(S)). The U.S. force fares best in those scenarios in which its commander concentrates his combat power and thwarts the Japanese surprise attack (scenarios 3(NS) and 4(NS)).

5. Conclusions

Using the model to explore and evaluate the U.S. commander's tactical options at the Battle of Savo Island has demonstrated its value as a tactical planning tool. The model's results clearly demonstrated that the scenario in which the U.S. force fared the worst was the one which most closely resembled how the Americans actually fought the battle. Flaws in the U.S. commander's tactical plans were, therefore, clearly indicated. Additionally, the model's results indicated the best alternative: concentrate combat power and be vigilant. Had the U.S. commander used the model in the hours prior to the battle, he would have undoubtedly reevaluated his tactical plans.

VI. SUMMARY AND CONCLUSIONS

A. MODEL DEVELOPMENT

A naval battle model has been developed which incorporates the essence of Hughes' tactical theory. Naval forces are portrayed as aggregations of the staying power and combat power of heterogeneous mixes of ships. Attrition is modeled as a force-on-force process and is suffered via continuous fire and/or through the impact of pulse weapons. User variation of inputs concerning the time, strength, target and duration of each force's fire allows analysis of the impact of C^2 and scouting effectiveness on battle dynamics.

B. DATA COLLECTION AND MODEL VALIDATION

Data was collected on fourteen twentieth century naval battles in order to compute model input parameters representing the forces involved in each battle and their interaction. For each battle, the model was run using the parameters computed from historical data and the resulting losses in each force's FC and FP, as predicted by the model, were recorded. FC and FP loss intervals were computed for both forces in each battle. The lower limit of a theoretical combat power loss interval represents the amount of theoretical combat power (pulse or continuous) carried by all platforms of a force suffering at least a firepower kill. The

upper limit represents the amount of theoretical combat power carried by all platforms of a force suffering at least some damage. The model was deemed to have produced a credible result for a battle if its predicted losses in FC and FP for each force fell within their corresponding loss intervals.

Of the 40 theoretical combat power loss percentages produced by model runs incorporating data from each of the fourteen battles, only two deviated significantly from their corresponding loss intervals. Investigation revealed that these deviations were anomalies peculiar to a particular platform in each battle and not to a fundamental model weakness. The model, therefore, was determined to be a fair representation of reality.

C. APPLICATION OF THE MODEL AS A PLANNING TOOL

The model's potential for application as a tactical planning tool was explored by using it to evaluate the tactical options of the U.S. commander at the Battle of Savo Island. Model input parameters representing the SP, FC and FP of the Japanese force were computed based on the U.S. commander's estimate of its size, composition and capabilities prior to the battle. Four scenarios were developed, each representing a variation in U.S. tactics including:

- Concentration of combat power.
- Division of forces to cover all possible geographic lines of approach available to the Japanese.

- Employment of torpedoes.
- Implications of a Japanese surprise attack.

Results of model runs of each scenario clearly indicated that the U.S. commander should have concentrated his combat power at Savo Island and increased his force's vigilance against the possibility of surprise attack. Although it was the U.S. commander's plan to divide his force into three smaller groups, use of the model prior to the battle would probably have forced him to rethink his tactics. The model's utility as a tactical planning tool has, therefore, been demonstrated.

D. RECOMMENDATIONS FOR FURTHER RESEARCH

Additional study should be conducted to develop the model further so that it can be put to practical use by fleet tacticians. The following are suggested topics of immediate interest:

- Incorporate modern platforms and weapons into the survivability analysis. Changes both in weapon systems and naval architecture since World War II make this an essential step in perfecting the model
- Improve the analysis of carrier battles by including the escort vessels into the aggregations of combat power and staying power. In particular, an analysis of their contribution to anti-air warfare with a view toward enriching the model with the incorporation of defensive combat power is needed.
- Conduct an analysis of engagements involving carrier airpower vs. land based airpower to discover if the model can be modified and enriched for use in analysis of this type of scenario.

APPENDIX A PLATFORM SURVIVABILITY ANALYSIS

A. INTRODUCTION

In order to develop a method of estimating the staying power of any given platform, it was necessary to gather and analyze data on platforms which had suffered firepower kills in combat. This appendix describes how the platform survivability model (Chapter I, equation (1)) was developed from analysis of a data set of 75 platforms which suffered firepower kills in World Wars I and II.

B. DATA COLLECTION

To be incorporated into the data set, a platform had to meet three criteria:

- Damage sustained caused a loss in mobility or firepower sufficient to prevent the platform from fulfilling its mission in battle.
- Damage sustained was not sufficient to sink the platform or warrant its destruction by friendly forces.
- Extent of damage was not such that "it took a miracle" to save it.

The first criterion ensures selection of platforms which suffered firepower kills while the second and third criteria reduce the number of platforms in the data set which sustained more damage than necessary to inflict a firepower kill.

The raw data collected for each platform in the data set included:

- Platform full load displacement.
- TNT explosive weight of each type of weapon which damaged the platform.
- Number of hits of each type of weapon which damaged the platform.

Table A-1 summarizes the data used in this analysis.

C. BASIC STRUCTURE OF THE MODEL

The goal of the analysis was to model the number of standard weapon hits necessary to inflict a firepower kill on a platform as a function of that platform's full load displacement:

$$N_i = a + b \times f(d_i) \tag{1}$$

where

N_i = number of standard weapon hits necessary to inflict a firepower kill on platform i.

$f(d_i)$ = function of the full load displacement of platform i (d_i).

a,b = coefficients of the linear model.

Using $f(d_i)$ as the explanatory variable in the model was intuitively appealing since it is reasonable to assume that the amount of protection and watertight integrity built into a platform is reflected in some degree by its full load displacement.

TABLE A-1 PLATFORM SURVIVABILITY ANALYSIS DATA BASE

NAME	FULL LOAD DISPL.	DATE	WEAPON	TNT EXPL WGT	# HITS
PLATFORMS DAMAGED BY TORPEDOES					
SCHARNHORST (G)	38900	08JUL40	21" MKIX(GB)	727	1
GNEISENAU (G)	38900	08APR41	18" MKXII(GB)	387	1
VENETO (I)	45029	27MAR41	18" MKXII(GB)	387	3
LITTORIO (I)	45236	11NOV40	18" MKXII(GB)	387	3
VENETO (I)	45029	15NOV41	21" MKVIII(GB)	722	1
INDEPENDENCE (US)	14751	20NOV43	18" TY91(J)	576	1
INTREPID (US)	34881	17FEB44	18" TY91(J)	576	1
ARETHUSA (GB)	7400	15NOV42	18" LT1 (G)	571	1
FIJI (GB)	10450	01SEP40	21" G7ET2(G)	858	1
LIVERPOOL (GB)	11650	30OCT40	21" G7ET2(G)	858	1
NEW ORLEANS (US)	12463	30NOV42	24" TY93 (J)	1056	1
HOUSTON (US)	14131	16OCT44	18" TY97 (J)	576	2
DENVER (US)	14131	13NOV43	18" TY97 (J)	576	1
LUTZOW (G)	16100	25JUN40	21" MKVIII(GB)	722	1
NURNBERG (G)	8400	13DEC39	21" MKVIII(GB)	722	1
GLASGOW (GB)	11350	01DEC40	17.7" LT1 (G)	571	2
COVENTRY (GB)	5240	31MAY41	21" G7ET2 (G)	858	1
CAPETOWN (GB)	5180	15FEB41	21" G7ET2 (G)	858	1
MANCHESTER (GB)	11650	23JUL41	17.7" LT1 (G)	571	1
PHOEBE (GB)	6850	23OCT42	17.7" LT1 (G)	571	1
CLEOPATRA (GB)	6850	21AUG43	21" G7ET5 (G)	788	1
CHICAGO (US)	11420	08AUG42	24" TY93 (J)	1056	1
PENSACOLA (US)	11512	30NOV42	24" TY93 (J)	1056	1
ST LOUIS (US)	12207	12JUL43	24" TY93 (J)	1056	1
KUMANO (J)	11000	20JUL43	22.4" MK13(US)	865	1
AGANO (J)	8534	11NOV43	22.4" MK13(US)	865	1
MYOKO (J)	13668	25OCT44	21" MK14 (US)	964	1
KUMANO (J)	11000	25OCT44	21" MK15 (US)	1234	1
TAMA (J)	5832	25OCT44	22.4" MK13 (US)	865	1
KEARNEY (GB)	2395	16OCT41	21" G7ET2 (G)	858	1
HAMBLETON (GB)	2395	11NOV42	21" G7ET2 (G)	858	1
SELFRIDGE (US)	2597	06OCT43	21" TY95 (J)	873	1
KELLY (GB)	2348	09MAY40	21" G7ET2 (G)	858	1
KISUMI (J)	2370	05JUL42	21" MK14 (US)	642	1
HATSUKAZI (J)	1900	10JAN43	21" MK14 (US)	642	1
PORTLAND (US)	12755	12NOV42	24" TY93 (J)	1056	1
JUNEAU (US)	8340	12NOV42	24" TY93 (J)	1056	1

TABLE A-1 PLATFORM SURVIVABILITY ANALYSIS DATA BASE (continued)

PLATFORMS DAMAGED BY BOMBS

ITALIA (I)	45236	09SEP43	FX 1400 (G)	732	1
ILLUSTRIOUS (GB)	29240	19JUN41	500kg AP (G)	209	9.5
			1000kg AP (G)	348	1
SHOKAKU (J)	32105	08MAY42	1000lb HC (US)	660	2
ZUIKAKU (J)	32105	19JUN44	1000lb HC (US)	660	4
SHOKAKU (J)	32105	26OCT42	1000lb HC (US)	660	4
ZUIHO (J)	14200	26OCT42	500lb HC (US)	307	2
RYUHO (J)	16700	19MAR45	500lb HC (US)	307	3
AMAGI (J)	22800	24JUL45	1000lb HC (US)	660	3
UGANDA (GB)	10450	11SEP43	FX1400 (G)	732	1
MARBLEHEAD (US)	7050	04FEB42	250kg SAP (J)	147	2.5
MOGAMI (J)	13230	04JUN42	500lb HC (US)	307	4
MAYA (J)	15781	[illegible]2NOV43	500lb HC (US)	307	1
NAGANAMI (J)	2520	11NOV43	500lb HC (US)	307	1.5
SHAW (US)	1110	07DEC41	250kg SAP (J)	147	3
MAYRANT (GB)	2250	26JUL43	500kg (G)	211	.5
MINEGUMO (J)	2370	05OCT42	500lb HC (US)	307	1
MATSUYAKI (J)	2389	17OCT42	500lb HC (US)	307	1
ISONAMI (J)	2389	01DEC42	500lb HC (US)	307	1.5
NOWAKI (J)	2500	07DEC42	500lb HC (US)	307	1.5

TABLE A-1 PLATFORM SURVIVABILITY ANALYSIS DATA BASE (continued)

PLATFORMS DAMAGED BY GUNFIRE

SCHARNHORST (G)	38900	23DEC43	14"/45 MKVII(G)	127	13
SOUTH DAKOTA (US)	44519	14NOV42	14"45 (J)	110	1
			8"/50 II (J)	23	18
			6" (J)	12	5
			5"/40 (J)	4	1
HIEI (J)	31785	12NOV42	8"/55 MK12 (US)	21	12
			5"/38 MK12 (US)	8	38
VON DER TANN (G)	21700	31MAY16	15"/42 MK1 (GB)	153	2
			13.5"/45 (GB)	112	2
WARSPITE (GB)	31500	31MAY6	12" SKL 50	66	13
			11" SKL 50	50	2
EXETER (GB)	10490	13DEC39	11"/54 C28 (G)	49	7
AOBA (J)	10651	12OCT42	5"/25 MK10 (US)	8	3
			8"/55 MK12 (US)	21	40
BOISE (US)	12207	12OCT42	8"/50II (J)	23	4
			5"/50 (J)	4	1
SAN FRANCISCO (US)	12463	12NOV42	14"/45 (J)	110	2
			5.5"/50 (J)	4	43
ONSLOW (GB)	2270	24DEC42	8"/60 C34 (G)	15	3
RALPH TALBOT (US)	2245	08AUG42	8"/50 II (J)	23	4
AARON WARD (US)	2395	12NOV42	5"/40 (J)	4	1
ACASTA (GB)	1300	31MAY16	6" SKL 45 (G)	7	2
BROKE (GB)	1250	31MAY16	6" SKL 45 (G)	7	2
			4" SKL 45 (G)	3	7
ONSLOW (GB)	1250	31MAY16	4" SKL 45 (G)	3	2
DEFENDER (GB)	990	31MAY16	12" SKL 50 (G)	66	1
GWIN (US)	2395	14NOV42	5.5" 50 (J)	8	3
NORFOLK (US)	14600	23DEC43	11"/54 C28 (G)	49	2
EXETER (GB)	11000	27FEB42	8"/50 II (J)	23	1

D. DATA ANALYSIS

1. Computing the Explanatory and Response Variables

The first step in the process of data analysis was to compute the explanatory variables, $f(d_i)$, and the response variables, N_i, from the raw data.

a. Explanatory Variables

Several functions of d_i were evaluated such as:

$$f(d_i) = d_i^{1/2} \tag{2}$$

$$f(d_i) = d_i^{1/3} \tag{3}$$

$$f(d_i) = \ln d_i \tag{4}$$

A set of explanatory variables, $\{f(d_i)\}$, was computed from the raw data set, $\{d_i\}$, for each function under consideration.

b. Response Variables

The standard weapon chosen for the analysis was the U.S. World War II vintage 1000 pound heavy case bomb. This bomb carried a warhead with explosive weight equal to 660 pounds of TNT. Raw data on the number of hits of particular weapons received by each platform in the data set were converted into the number of TPBE hits received as follows:

$$N_i = \frac{\sum_j (\text{weight}_j \times N_{ij} \times \text{Wt})}{660 \text{ lbs.}} \tag{5}$$

where:

N_i = # TPBE hits taken by platform i in the data set.

weight_j = TNT explosive weight of weapon j taken by platform i.

N_{ij} = # hits of weapon j taken by platform i (a near miss which caused damage was considered 0.5 of a hit).

Wt = weight assigned whose value is determined by whether weapon j is a bomb, torpedo, or shell.

Examples of weapon "weight schemes" considered include:

$$Wt = \begin{cases} 1.0 \text{ for bombs} \\ 1.25 \text{ for shells} \\ 1.5 \text{ for torpedoes} \end{cases} \quad \text{or} \quad Wt = \begin{cases} 1.0 \text{ for bombs} \\ 1.25 \text{ for torpedoes} \\ 2.5 \text{ for shells} \end{cases}$$

Sets of response variables, $\{N_i\}$, were computed from the raw data set using each weight scheme considered.

2. **Analysis Procedure**

Scatter plots were examined. Each scatter plot paired a particular $\{f(d_i)\}$ with a $\{N_i\}$ computed using a particular weighting scheme. A set of ordered pairs, $\{f(d_i), N_i\}$, was put aside for further analysis if visual examination of its scatter plot indicated a possible linear relationship between $f(d_i)$ and N_i.

For each set of ordered pairs set aside, a model was constructed in the form of equation (1). Least squares estimates of the coefficients (a) and (b) were computed. A model was given further consideration if:

- A 95% confidence interval on the estimate of (a) included zero.

- A 95% confidence interval on the estimate of (b) did not include zero.

This result indicated that there was a linear relationship between N_i and $f(d_i)$ while at the same time allowed formulation of a model of the form:

$$N_i = b \times f(d_i) \tag{6}$$

This model is much more appealing than equation (1) because it implies that the number of TPBE hits necessary to inflict a firepower kill on a platform whose d_i equals zero is zero rather than a constant (a) greater than zero.

For each model still under consideration, a chi-square goodness-of-fit test was performed on its residuals to test:

$$H_0: e_i \approx N(0, \sigma)$$

A model was given further consideration if the significance level of the test was greater than 0.05.

The final test performed on the remaining candidate models involved further visual analysis. For each model, scatter plots of data points for each weapon category (bomb, torpedo, and shell) were superimposed on a plot of the model line. The model selected was the one in which it appeared that the data points for each weapon type were most randomly scattered about the line.

3. Final Model

The function of full load displacement and the weapon weight scheme incorporated into the model are:

$$f(d_i) = (d_i)^{1/3} \tag{7}$$

$$Wt = \begin{cases} 1.0 \text{ for bombs} \\ 1.25 \text{ for torpedoes} \\ 2.5 \text{ for shells} \end{cases} \tag{8}$$

Table A-2 summarizes the least squares estimates and corresponding 95% confidence intervals of the coefficients (a) and (b) for the model incorporating (7) and (8).

TABLE A-2 LEAST SQUARES ESTIMATES OF MODEL COEFFICIENTS

PARAMETERS	LSE	95% CONFIDENCE LIMITS LOWER	UPPER
a	-0.313	-0.958	0.331
b	0.083	0.055	0.111

Since (a)'s confidence interval includes zero, it's estimate was set equal to zero and the LSE of (b) was recomputed. The final form of this model, therefore, is:

$$N_i = 0.070369 \times (d_i)^{1/3} \tag{9}$$

The chi-square goodness of fit test on the model's residuals yielded a significance level of 0.196. Figure 1 is a scatter plot of the set of ordered pairs $\{(d_i^{1/3}, N_i)\}$ superimposed over the model line.

4. Model Weaknesses

Figures 2, 3, and 4 are scatter plots of those platforms in the data set damaged by bombs, torpedoes, and shells respectively overlaid on the model line.

While the data points appear, in all three cases, to be fairly evenly scattered around the model line, there are

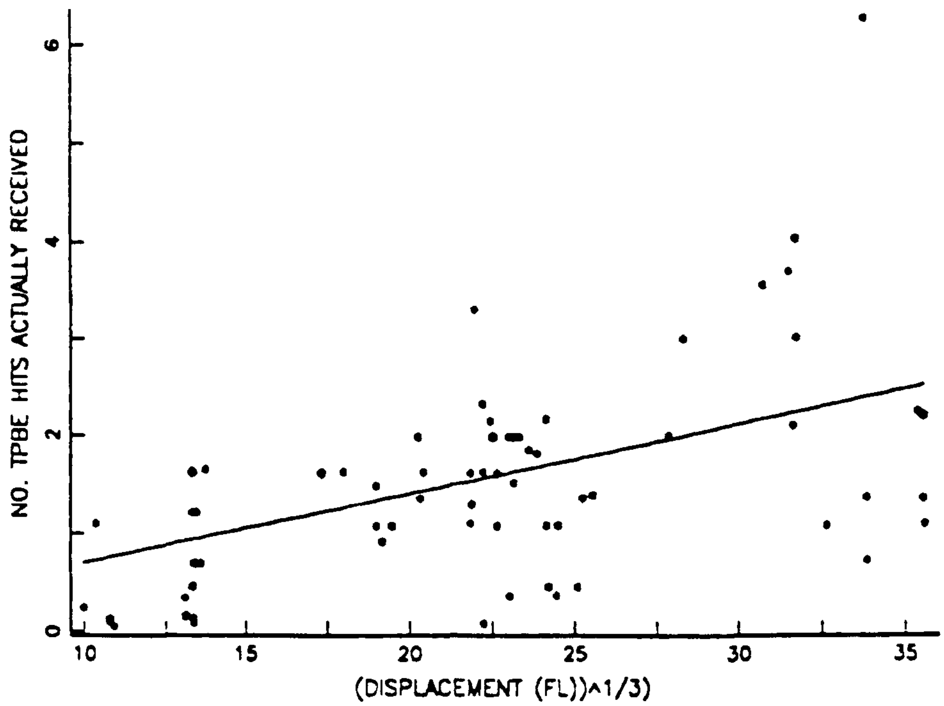

Figure 1. Entire Data Set Plotted Over Model Line

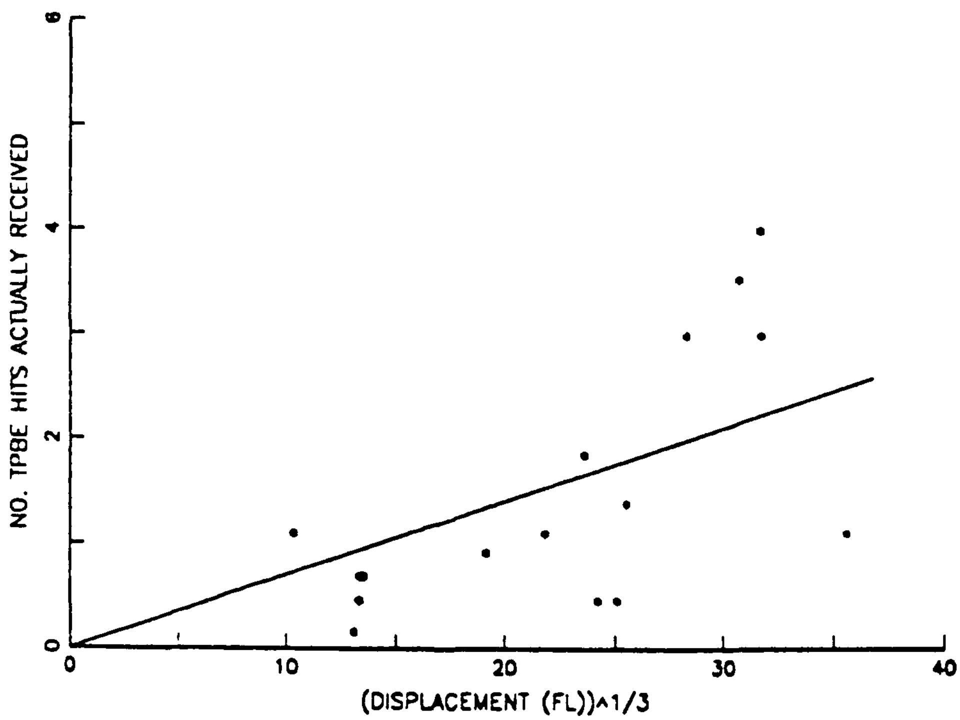

Figure 2. Bomb Damaged Platforms Plotted Over Model Line

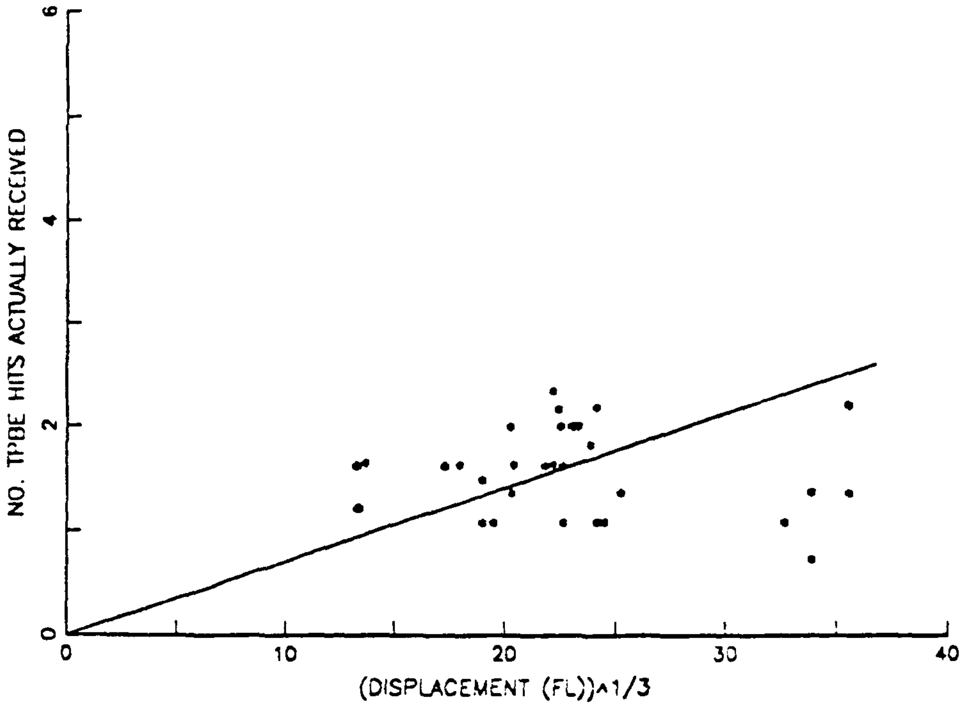

Figure 3. Torpedo Damaged Platforms Plotted Over Model Line

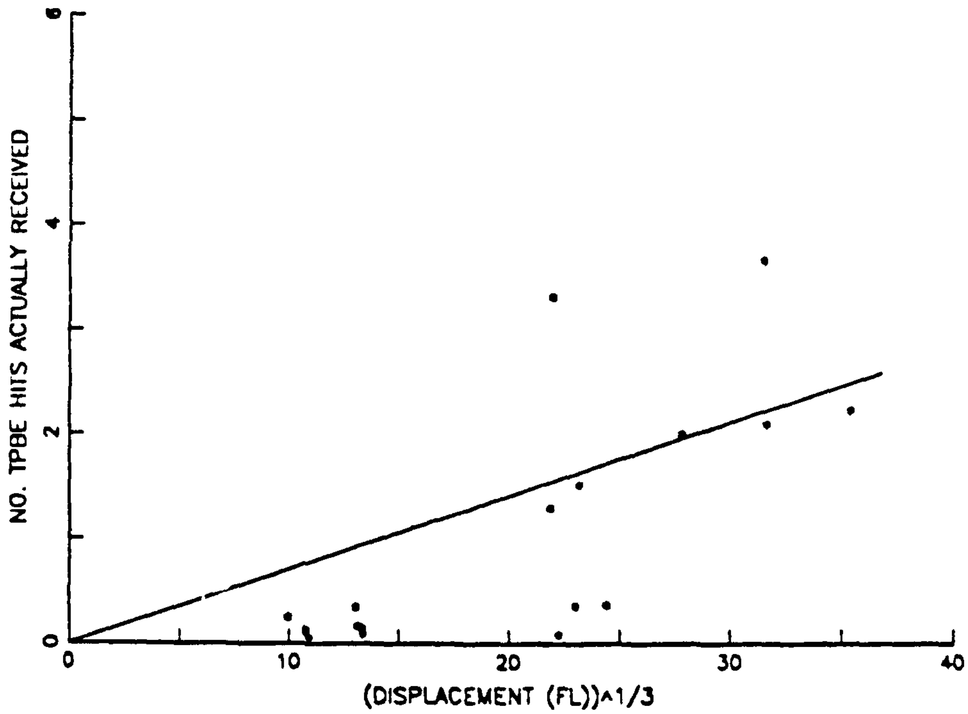

Figure 4. Shell Damaged Platforms Plotted Over Model Line

some problems. From Figure 3, it is clear that larger platforms suffer more heavily from torpedoes than predicted by the model. From Figure 4, it is clear that small platforms suffer more heavily from gunfire than predicted by the model. Figure 3 also clearly indicates that there exists some bias in the data set as a result of overkill of smaller platforms. Those destroyers which suffered firepower kills as a result of a hit by a torpedo with high explosive yield would probably have been killed by a torpedo with lower yield. It was not possible to remove these sources of bias without making the survivability model too complicated to be incorporated into the naval battle model.

E. CONCLUSIONS

The foregoing analysis indicates that the model will produce reasonable results. It is important to bear in mind that the purpose of the analysis was not to draw any firm conclusions about platform staying power. Its purpose was to produce a credible estimate of staying power to be used as a battle model input.

APPENDIX B WEAPON AND PLATFORM DATA BASE

A. SUMMARY

The following tables (Tables B-1 through B-18) incorporate the weapon and platform characteristics used in the model validation process described in Chapter IV. Table B-1 lists common warhead explosives and their ballistic mortar strength values. These values were used to convert the explosive weight of a particular warhead into the equivalent explosive weight in pounds of TNT. All explosive weights are expressed in terms of the number of pounds of TNT necessary to produce the yield of the weapon's warhead.

Heavy and medium calibre guns could fire both armor piercing (AP) and high capacity (HC) shells. These shells were often employed interchangeably in battle. HC shells had higher explosive weights than AP shells which compensated for their lack of the armor piercing characteristics.

The explosive weights assigned to shells in these tables are those of the HC shells. They were used since their destructive power was determined almost exclusively by the sizes of their explosive charges (without the additional factor of the armor piercing characteristic). Their destructive power, therefore, was more easily quantified than those of AP shells.

The following abbreviations are used throughout:

EW = TNT-equivalent explosive weight of warhead.

ROF = gun's rate of fire in rounds per minute.

NS = number of salvoes carried by the platform.

TABLE B-1 EXPLOSIVES

EXPLOSIVE	BALLISTIC MORTAR STRENGTH (% TNT)
Amatol	123
Picric Acid	107
Shellite	91
TNT	100
TORPEX	150
Type 91	108
Type 97	98
Type 98	109

TABLE B-2 GUN DATA

NATIONALITY	SIZE/ CALIBRE	DESIGNATION	EXPL.	EW	ROF
<u>WORLD WAR I</u>					
BRITISH	13.5"/45	MKV	TNT	111.76	1.5
	12.0"/45	MKX	TNT	67.76	2.0
	9.2"		TNT	30.38	4.0
	6.0"/50	MKXIV	TNT	7.99	7.0
	6.0"/45	MKVII	TNT	7.99	7.0
GERMAN	12.0"	SKL 50	TNT	66.37	1.0
	11.1"	SKL 50	TNT	49.50	1.5
	8.2"	SKL 45	TNT	17.82	4.0
	5.9"	SKL 45	TNT	7.48	7.0
	4.1"	SKL 45	TNT	2.86	20.0
<u>WORLD WAR II</u>					
BRITISH	8.0"	MKVIII	Shellite	20.43	5.5
	6.0"	BL MKXI	Shellite	7.99	5.0
GERMAN	11.0	SKC 28	TNT	49.17	3.5
UNITED STATES	16.0"/45	MK6	TNT	161.19	2.0
	8.0"/55	MK12	TNT	22.07	4.0
	6.0"/52	MK16	TNT	13.61	9.8
	5.0"/38	MK12	TNT	7.85	17.5
JAPAN	14.0"/45		Type 91	110.00	1.8
	8.0"/50	II	Type 91	23.01	4.0
	5.5"/50		Picric Acid	8.45	6.0
	5.0"/50		Type 91	4.20	7.5
	4.7"		Type 91	6.58	10.0
	4.0"/65		Type 91	3.12	18.0

TABLE B-3 TORPEDO AND BOMB DATA

NATIONALITY	SIZE	DESIGNATION	EXPLOSIVE	EW
<u>TORPEDOES</u>				
BRITISH	21.0"	MKIX	TNT	727.10
UNITED STATES	22.4"	MK13	TNT	400.40
	22.4"	MK13	TORPEX	864.60
	21.0"	MK15	TNT	822.80
	21.0"	MK15	TORPEX	1234.20
JAPANESE	24.0"	Type 93 Mod I	Type 97	1056.44
	21.0"	6 year type	TNT	440.00
	18.0"	Type 91 Mod 2	Type 98	491.59
<u>BOMBS</u>				
UNITED STATES	1000 lb.	MK 9/ Heavy Case	Amatol	660.00
	500 lb.	MK 12/ Heavy Case	Amatol	307.36
JAPANESE	250 kg.	Type 99 SAP	Type 91	142.70

TABLE B-4 AIRCRAFT DATA

NATIONALITY	NAME	DESIGN-ATION	WEAPON LOAD-OUT
UNITED STATES	DAUNTLESS	SBD-3	1-1000 lb. HC Bomb
	DAUNTLESS(Scout)	SBD-3	1-500 lb. HC Bomb
	DEVASTATOR	TBD-1	1-22.4" Torpedo
	AVENGER	TBF-1	1-22.4" Torpedo
JAPAN	VAL	D3A1 11	1-250 kg. SAP Bomb
	KATE	B5N1 12	1-18" Torpedo

TABLE B-5 CORONEL--PLATFORM DATA

NATIONALITY	NAME	MAIN BATTERY GUNS	DISPL. (f.l. tons)
BRITISH	GOOD HOPE	2-9.2", 16-6"/45 MKVII	14150
	MONMOUTH	14-6.0"/45 MKVII	9800
	GLASGOW	2-6.0"/50 MKXIV	5300
GERMAN	SCHARNHORST	8-8.2" SKL 45	12781
	GNEISENAU	8-8.2" SKL 45	12781
	LEIPZIG	10-4.1" SKL 45	4268
	DRESDEN	10-4.1" SKL 45	3756

TABLE B-6 FALKLAND ISLANDS--PLATFORM DATA

NATIONALITY	NAME	MAIN BATTERY GUNS	DISPL. (f.l.Tons)
BRITISH	INVINCIBLE	8-12.0"/45 MKX	20078
	INFLEXIBLE	8-12.0"/45 MKX	20078
GERMANS	SCHARNHORST	8-8.2" SKL 45	12781
	GNEISENAU	8-8.2" SKL 45	12781

TABLE B-7 DOGGER BANK--PLATFORM DATA

NATIONALITY	NAME	MAIN BATTERY GUNS	DISPL. (f.l. tons)
BRITISH	LION	8-13.5"/45 MKV	29680
	PRINCESS ROYAL	8-13.5"/45 MKV	29680
	TIGER	8-13.5"/45 MKV	35710
	NEW ZEALAND	8-12.0"/45 MKX	22080
	INDOMITABLE	8-12.0"/45 MKX	20078
GERMAN	SEYDLITZ	10-11.1" SKL 50	28100
	DERFFLINGER	8-12.0" SKL 50	30700
	MOLTKE	10-11.1" SKL 50	25300

TABLE B-8 RIVER PLATE--PLATFORM DATA

NATIONALITY	NAME	MAIN BATTERY GUNS	DISPL. (f.l.tons)
BRITISH	EXETER	6-8" MK VIII	10490
	AJAX	8-6" BL MKXI	9280
	ACHILLES	8-6" BL MKXI	9280
GERMAN	GRAF SPEE	6-11" SKC 28	16200

TABLE B-9 CORAL SEA--PLATFORM DATA

NATIONALITY	NAME	AIRCRAFT	DISPL. (f.l. tons)
UNITED STATES	LEXINGTON	17-DAUNTLESSES 17-DAUNTLESS Scouts 11-DEVASTATORS	43055
	YORKTOWN	17-DAUNTLESSES 17-DAUNTLESS Scouts 10-DEVASTATORS	25484
JAPANESE	SHOKAKU	17-VALS 13-KATES	32105
	ZUIKAKU	16-VALS 12-KATES	32105

TABLE B-10 MIDWAY--PLATFORM DATA

NATIONALITY	NAME	AIRCRAFT	DISPL. (f.l. tons)
UNITED STATES	YORKTOWN	18-DAUNTLESSES 19-DAUNTLESS Scouts 13-DEVASTATORS	25484
	ENTERPRISE	19-DAUNTLESSES 19-DAUNTLESS Scouts 14-DEVASTATORS	25484
	HORNET	19-DAUNTLESSES 18-DAUNTLESS Scouts 15-DEVASTATORS	25484
JAPANESE	AKAGI	18-VALS 18-KATES	42750
	KAGA	18-VALS 27-KATES	43650
	HIRYU	18-VALS 18-KATES	21900
	SORYU	18-VALS 18-KATES	19800

TABLE B-11 SAVO ISLAND--PLATFORM DATA

NATIONALITY/ NAME	MAIN BATTERY BATTERY GUNS	TORPEDOES SIZE/DESIG	TORPEDOES # PER SALVO	TORPEDOES NS	DISPL. (f.l.tons)
UNITED STATES--					
VINCENNES	9-8.0"/55 MK12				12463
ASTORIA	9-8.0"/55 MK12				12463
QUINCY	9-8.0"/55 MK12				12463
CHICAGO	9-8.0"/55 MK12				11420
CANBERRA	8-8.0" MKVIII				14910
SAN JUAN	16-5.0"/38 MK12	21" MK15	4	2	8340
HOBART	8-6.0" BL MKXI	21" MKIX	4	2	9150
HELM	4-5.0"/38 MK12	21" MK15	8	2	2245
WILSON	4-5.0"/38 MK12	21" MK15	8	2	2250
PATTERSON	4-5.0"/38 MK12	21" MK15	8	2	2245
BAGLEY	4-5.0"/38 MK12	21" MK15	8	2	2245
MONSSEN	5-5.0"/38 MK12	21" MK15	10	1	2395
BUCHANON	5-5.0"/38 MK12	21" MK15	10	1	2395
BLUE	4-5.0"/38 MK12	21" MK15	8	2	2245
RALPH TALBOT	4-5.0"/38 MK12	21" MK15	8	2	2245
JAPANESE--					
AOBA	6-8.0"/50 II	24" TYPE 93	4	2	10651
KAKO	6-8.0"/50 II	24" TYPE 93	4	2	10341
KINUGASA	6-8.0"/50 II	24" TYPE 93	4	2	10651
FURUTAKA	6-8.0"/50 II	24" TYPE 93	4	2	10341
CHOKAI	10-8.0"/50 II	24" TYPE 93	8	2	14604
TENRYU	4-5.5"/50	21" 6 YR TYPE	6	1	4350
YUBARI	6-5.5"/50	24" TYPE 93	4	1	3141
YUNAGI	3-5.0"/50	21" 6 YR TYPE	4	1	1720

TABLE B-12 EASTERN SOLOMONS--PLATFORM DATA

NATIONALITY	NAME	AIRCRAFT	DISPL. (f.l. tons)
UNITED STATES	ENTERPRISE	18-DAUNTLESSES 18-DAUNTLESS Scouts 15-AVENGERS	25484
	SARATOGA	18-DAUNTLESSES 18-DAUNTLESS Scouts 15-AVENGERS	43055
JAPANESE	RYUHO	21-KATES	16700
	SHOKAKU	18-KATES 21-VALS	32105
	ZUIKAKU	18-KATES 20-VALS	32105

TABLE B-13 SANTA CRUZ ISLANDS--PLATFORM DATA

NATIONALITY	NAME	AIRCRAFT	DISPL. (f.l. tons)
JAPANESE	SHOKAKU	20-VALS 23-KATES	32105
	ZUIKAKU	27-VALS 18-KATES	32105
	ZUIHO	6-KATES	14200
	JUNYO	21-VALS 10-KATES	28300
UNITED STATES	ENTERPRISE	18-DAUNTLESSES 18-DAUNTLESS Scouts 12-AVENGERS	25484
	HORNET	18-DAUNTLESSES 18-DAUNTLESS Scouts 15-AVENGERS	43055

TABLE B-14 NAVAL BATTLE OF GUADALCANAL (SECOND NIGHT)--PLATFORM DATA

NATIONALITY/ NAME	MAIN BATTERY BATTERY GUNS	TORPEDOES SIZE/DESIG	TORPEDOES # PER SALVO	TORPEDOES NS	DISPL. (f.l. tons)
UNITED STATES--					
SOUTH DAKOTA	9-16.0"/45 MK6 10-5.0"/38 MK12				44519
WASHINGTON	9-16.0"/45 MK6 10-5.0"/38 MK12				44377
WALKE	5-5.0"/38 MK12	21" MK15	8	1	2313
BENHAM	4-5.0"/38 MK12	21" MK15	8	2	2250
PRESTON	5-5.0"/38 MK12	21" MK15	8	1.5	2103
GWIN	5-5.0"/38 MK12	21" MK15	10	1	2395
JAPANESE--					
SENDAI	7-5.5"/50	24" TYPE 93	4	2	7100
SHIKINAMI	6-5.0"/50	24" TYPE 93	9	1	2389
URANAMI	6-5.0"/50	24" TYPE 93	9	1	2389
AYANAMI	6-5.0"/50	24" TYPE 93	9	1	2389
NAGARA	7-5.5"/50	24" TYPE 93	4	2	5570
ASAGUMO	6-5.0"/50	24" TYPE 93	8	1	2370
TERUZUKI	8-4.0"/65	24" TYPE 93	4	1	3700
INAZUMA	4-5.0"/50	24" TYPE 93	9	1	2260
SHIRAYUKI	6-5.0"/50	24" TYPE 93	9	1	2389
KIRISHIMA	8-14.0"/45				31785
ATAGO	10-8.0"/50	24" TYPE 93	8	2	14604
TAKAO	10-8.0"/50	24" TYPE 93	8	2	14604
HATSUYUKI	6-5.0"/50	24" TYPE 93	9	1	2389
SAMIDARE	4-5.0"/50	24" TYPE 93	8	1	2075

TABLE B-15 TASSAFARONGA--PLATFORM DATA

NATIONALITY/ NAME	MAIN BATTERY BATTERY GUNS	TORPEDOES SIZE/DESIG	TORPEDOES # PER SALVO	TORPEDOES NS	DISPL. (f.l. tons)
UNITED STATES--					
MINNEAPOLIS	9-8.0"/55 MK12				12463
NEW ORLEANS	9-8.0"/55 MK12				12463
PENSACOLA	10-8.0"/55 MK12				11512
NORTHAMPTON	9-8.0"/55 MK12				11420
HONOLULU	15-6.0"/52 MK16				12207
FLETCHER	5-5.0"/38 MK12	21" MK15	10	1	2924
DRAYTON	5-5.0"/38 MK12	21" MK15	8	1.5	2103
MAURY	4-5.0"/38 MK12	21" MK15	8	2	2219
PERKINS	5-5.0"/38 MK12	21" MK15	8	1.5	2103
LAMSON	5-5.0"/38 MK12	21" MK15	8	1.5	2103
LARDNER	5-5.0"/38 MK12	21" MK15	10	1	2395
JAPANESE--					
TAKANAMI	4-5.0"/50	24" TYPE 93	8	1	2520
NAGANAMI	4-5.0"/50	24" TYPE 93	8	1	2520
MAKINAMI	4-5.0"/50	24" TYPE 93	8	1	2520
KUROSHIO	4-5.0"/50	24" TYPE 93	8	1	2450
OYASHIO	4-5.0"/50	24" TYPE 93	8	1	2450
KAGERO	4-5.0"/50	24" TYPE 93	8	1	2450
KAWAKAZE	4-5.0"/50	24" TYPE 93	8	1	2075
SUZUKAZE	4-5.0"/50	24" TYPE 93	8	1	2075

TABLE B-16 KOMANDORSKI ISLANDS--PLATFORM DATA

NATIONALITY/ NAME	MAIN BATTERY BATTERY GUNS	TORPEDOES SIZE/DESIG	# PER SALVO	NS	DISPL. (f.l. tons)
UNITED STATES--					
SALT LAKE CITY	10-8.0"/55 MK12				11512
RICHMOND	12-6.0"/52 MK16	21"MK15(TORPEX)	3	2	7050
BAILEY	5-5.0"/38 MK12	21"MK15(TORPEX)	10	1	2395
COGHLAN	5-5.0"/38 MK12	21"MK15(TORPEX)	10	1	2395
DALE	5-5.0"/38 MK12	21"MK15(TORPEX)	8	1	2064
MONAGHAN	5-5.0"/38 MK12	21"MK15(TORPEX)	8	1	2064
JAPANESE--					
NACHI	10-8.0"/50 II	24" TYPE 93	4	2	14743
MAYA	10-8.0"/50 II	24" TYPE 93	8	2	14604
ABUKUMA	7-5.5"/50	24" TYPE 93	4	2	5570
TAMA	7-5.5"/50	24" TYPE 93	4	2	5500
WAKABA	4-5.0"/50	24" TYPE 93	6	1	1802
HATSUSHIMO	4-5.0"/50	24" TYPE 93	6	1	1802

TABLE B-17 KULA GULF--PLATFORM DATA

NATIONALITY/ NAME	MAIN BATTERY BATTERY GUNS	TORPEDOES SIZE/DESIG	# PER SALVO	NS	DISPL. (f.l.tons)
UNITED STATES--					
HONOLULU	15-6.0"/52 MK16				12207
HELENA	15-6.0"/52 MK16				12207
ST LOUIS	15-6.0"/52 MK16				12207
NICHOLAS	5-5.0"/38 MK12	21"MK15(TORPEX)	10	1	2924
O'BANNON	5-5.0"/38 MK12	21"MK15(TORPEX)	10	1	2924
RADFORD	5-5.0"/38 MK12	21"MK15(TORPEX)	10	1	2924
JENKINS	5-5.0"/38 MK12	21"MK15(TORPEX)	10	1	2924
JAPANESE--					
NIITSUKI	8-4.0"/65	24" TYPE 93	4	1	3700
SUZUKAZI	4-5.0"/50	24" TYPE 93	8	1	2075
TANIKAZI	4-5.0"/50	24" TYPE 93	8	1	2450
AMAGIRI	4-5.0"/50	24" TYPE 93	9	1	2389
HATSUYUKI	4-5.0"/50	24" TYPE 93	9	1	2389
NAGATSUKI	2-4.7"	24" TYPE 93	6	1	1883
SATSUKI	2-4.7"	24" TYPE 93	6	1	1883

TABLE B-18 VELLA GULF--PLATFORM DATA

NATIONALITY/ NAME	MAIN BATTERY BATTERY GUNS	TORPEDOES SIZE/DESIG	# PER SALVO	NS	DISPL. (f.l. tons)
UNITED STATES--					
DUNLAP	5-5.0"/38 MK12	21"MK15(TORPEX)	8	1.5	2103
CRAVEN	4-5.0"/38 MK12	21"MK15(TORPEX)	8	2	2219
MAURY	4-5.0"/38 MK12	21"MK15(TORPEX)	8	2	2219
LONG	4-5.0"/38 MK12	21"MK15(TORPEX)	8	2	2250
STERETT	4-5.0"/38 MK12	21"MK15(TORPEX)	8	2	2250
STACK	4-5.0"/38 MK12	21"MK15(TORPEX)	8	2	2250
JAPANESE--					
SHIGURE	4-5.0"/50	24" TYPE 93	8	1	2075
KAWAKAZE	4-5.0"/50	24" TYPE 93	8	1	2075
ARASHI	4-5.0"/50	24" TYPE 93	8	1	2450
HAGIKAZE	4-5.0"/50	24" TYPE 93	8	1	2450

APPENDIX C PROGRAM LISTING AND SAMPLE OUTPUT FILE

A. PROGRAM LISTING

This program incorporates the naval battle model described in Chapter II. It was coded in FORTRAN 77 and implemented on the Naval Postgraduate School's IBM 3033 AP mainframe computer.

```
      PROGRAM BATTLE

**********************************************************************
*     THIS PROGRAM INCORPORATES A FORCE-ON-FORCE ATTRITION MODEL     *
*     OF NAVAL COMBAT.  THE USER COMPUTES INPUT PARAMETERS           *
*     REPRESENTING THE AGGREGATE STAYING POWER, THEORETICAL COMBAT   *
*     POWER AND WEAPON EFFECTIVENESS OF THE OPPOSING FORCES. THESE   *
*     VALUES ARE INPUTTED INTO THE PROGRAM ALONG WITH PARAMETERS     *
*     REPRESENTING THE INTERACTION OF THE OPPOSING FORCES IN THE     *
*     DESIRED BATTLE SCENARIO.  THE MODEL'S RESULTS ARE EXPRESSED    *
*     IN TERMS OF THE % STAYING POWER AND THEORETICAL COMBAT         *
*     POWER LOST BY EACH FORCE.                                      *
**********************************************************************

      INTEGER GA, GB, NWA, NWB, FIRECA(20), FIRECB(20), DURCA(20),
     +DURCB(20), FIREPA(20), FIREPB(20), NFAP, NFBP, SHTPA(10),
     +SHTPB(10), NBPF(10), NAPF(10), IMPA(20), IMPB(20), TGTPA(20,10),
     +TGTPB(20,10), PA, PB, JPA, JPB, NFA(10), NFB(10), SHTCA(20,10),
     +SHTCB(20,10), NACF(10), NBCF(10), TGTCA(20,10), TGTCB(20,10),
     +STOPCA(20), STOPCB(20), CA, JCA, CB, JCB, A, G, H, HA, HB, I, K,
     +L1, M, N

      REAL SA(10), SB(10), SAO, SBO, FCA(10), FCB(10), FPA(10,10),
     +FPB(10,10), PCA(10), PCB(10), TOTPFP, PULSEA(20), PULSEB(20),
     +PPA(20), PPB(20), LA(10), LB(10), SP, LPA(10), LPB(10), LCA(10),
     +LCB(10), L, FC, SATOT, SBTOT, FCATOT, FCBTOT, FPATOT, FPBTOT,
     +TLSA, TLSB, TLCA, TLCB, TLPA, TLPB, FPAO, FPBO, FCAO, FCBO,
     +BPA, BPB

      DATA FIRECA, FIRECB, DURCA, DURCB /20*0, 20*0, 20*0, 20*0/
      DATA FIREPA, FIREPB, NBPF, NAPF /20*0, 20*0, 10*0, 10*0/
      DATA IMPA, IMPB, NFA, NFB, NACF /20*0, 20*0, 10*0, 10*0, 10*0/
      DATA NBCF, STOPCA, STOPCB, SHTPA /10*0, 20*0, 20*0, 10*0/
      DATA SHTPB, SA, SB, FCA, FCB /10*0, 10*0, 10*0, 10*0, 10*0/
      DATA PCA, PCB, LA, LB, LPA /10*0, 10*0, 10*0, 10*0, 10*0/
      DATA LPB, LCA, LCB, PULSEA, PULSEB /10*0, 10*0, 10*0, 20*0, 20*0/
      DATA PPA, PPB /20*0, 20*0/
      DATA SHTCA, SHTCB, TGTCA, TGTCB /200*0, 200*0, 200*0, 200*0/
      DATA FPA, FPB /100*0, 100*0 /

      SAO = 0
      SBO = 0
      FCAO = 0
      FCBO = 0
```

```
      FPA0 = 0
      FPB0 = 0

      PRINT*, 'ENTER THE FOLLOWING:'
      PRINT*
      PRINT*, 'NUMBER OF GROUPS INTO WHICH A AND B ARE DIVIDED.'
      READ*, GA, GB
      PRINT*, 'STAYING POWER OF EACH A GROUP.'
      READ*, (SA(I), I = 1, GA)
      PRINT*, 'STAYING POWER OF EACH B GROUP.'
      READ*, (SB(I), I = 1, GB)
      DO 10 I = 1, GA
         SA0 = SA0 + SA(I)
10    CONTINUE
      DO 20 I = 1, GB
         SB0 = SB0 + SB(I)
20    CONTINUE
      PRINT*, 'THEORETICAL CONTINUOUS COMBAT POWER OF EACH A GROUP.'
      DO 21 I = 1, GA
         READ*, FCA(I)
         FCA0 = FCA0 + FCA(I)
21    CONTINUE
      PRINT*, 'THEORETICAL CONTINUOUS COMBAT POWER OF EACH B GROUP.'
      DO 22 I = 1, GB
         READ*, FCB(I)
         FCB0 = FCB0 + FCB(I)
22    CONTINUE
      PRINT*, 'NUMBER OF PULSED WEAPONS TYPES IN FORCES A AND B.'
      READ*, NWA, NWB
      IF (NWA.EQ.0) GOTO 31
      PRINT*, 'THEORETICAL PULSE COMBAT POWER'
      PRINT*, 'OF EACH PULSE WEAPON IN A:'
      PRINT*
      DO 30 I = 1, GA
         PRINT*, 'GROUP ', I
         DO 23 J = 1, NWA
            READ*, FPA(I,J)
            FPA0 = FPA0 + FPA(I,J)
23       CONTINUE
30    CONTINUE
      IF (NWB.EQ.0) GOTO 45
      PRINT*, 'THEORETICAL PULSE COMBAT POWER'
      PRINT*, 'OF EACH PULSE WEAPON IN B:'
      PRINT*
      DO 40 I = 1, GB
         PRINT*, 'GROUP ', I
         DO 31 J = 1, NWB
            READ*, FPB(I,J)
            FPB0 = FPB0 + FPB(I,J)
31       CONTINUE
40    CONTINUE

45    PRINT*, 'DOES THIS ENGAGEMENT INCLUDE CONTINUOUS FIRE?'
      PRINT*, '(1 IF YES, 0 IF NO)'
      READ*, A
      IF (A.EQ.0) GOTO 80
      PRINT*, 'ENTER CONTINUOUS WEAPON EFFECTIVENESS'
      PRINT*, 'FOR EACH A GROUP.'
      READ*, (PCA(I), I = 1, GA)
      PRINT*, 'ENTER CONTINUOUS WEAPON EFFECTIVENESS'
      PRINT*, 'FOR EACH B GROUP.'
      READ*, (PCB(I), I = 1, GB)
      PRINT*, 'ENTER THE NUMBER OF TIMES A WILL EMPLOY'
      PRINT*, 'CONTINUOUS FIRE (INCLUDING 0).'
      READ*, M
```

```
      IF (M.LE.0) GOTO 60
      PRINT*, 'ENTER THE INCREMENTS AT WHICH A WILL OPEN'
      PRINT*, 'CONTINUOUS FIRE AND THE DURATION OF FIRE.'
      DO 50 I = 1, M
         READ*, FIRECA(I), DURCA(I)
50    CONTINUE
60    PRINT*, 'ENTER THE NUMBER OF TIMES B WILL EMPLOY'
      PRINT*, 'CONTINUOUS FIRE (INCLUDING 0).'
      READ*, M
      IF (M.LE.0) GOTO 80
      PRINT*, 'ENTER THE INCREMENTS AT WHICH B WILL OPEN'
      PRINT*, 'CONTINUOUS FIRE AND THE DURATION OF FIRE.'
      DO 70 I = 1, M
         READ*, FIRECB(I), DURCB(I)
70    CONTINUE

80    PRINT*, 'DOES THIS ENGAGEMENT INCLUDE PULSED FIRE?'
      PRINT*, '(1 IF YES, 0 IF NO).'
      READ*, A
      IF (A.EQ.0) GOTO 100
      PRINT*, 'ENTER THE NUMBER OF TIMES A WILL FIRE (INCLUDING 0).'
      READ*, M
      IF (M.EQ.0) GOTO 90
      PRINT*, 'ENTER THE TIME INCREMENTS AT WHICH A WILL OPEN FIRE.'
      READ*, (FIREPA(I), I = 1, M)
90    PRINT*, 'ENTER THE NUMBER OF TIMES B WILL FIRE (INCLUDING 0).'
      READ*, M
      IF (M.EQ.0) GOTO 100
      PRINT*, 'ENTER THE TIME INCREMENTS AT WHICH B WILL OPEN FIRE.'
      READ*, (FIREPB(I), I = 1, M)

100   PRINT*, 'DO YOU WISH TO KNOW:'
      PRINT*
      PRINT*, 'THE RESULTS OF THE BATTLE AFTER A GIVEN NUMBER OF'
      PRINT*, 'INCREMENTS? (1 IF YES, 0 IF NO).'
      READ*, A
      IF (A.EQ.1) GOTO 110
      PRINT*, 'THE OUTCOME OF A FIGHT TO A PREDETERMINED'
      PRINT*, '% LOSS IN STAYING POWER?'
      PRINT*, '(1 IF YES, 0 IF NO).'
      READ*, A
      IF (A.EQ.1) GOTO 120
      STOP

110   PRINT*, 'ENTER THE NUMBER OF INCREMENTS TO BE CONSIDERED.'
      READ*, N
      BPA = 2 - 3
      BPB = 2 - 3
      GOTO 121

120   N = 1000
      PRINT*, 'ENTER THE MAXIMUM PERMISSIBLE % LOSS IN STAYING'
      PRINT*, 'POWER OF FORCE A.'
      READ*, BPA
      BPA = SA0 - ((BPA / 100) * SA0)
      PRINT*, 'ENTER THE MAXIMUM PERMISSIBLE % LOSS IN STAYING'
      PRINT*, 'POWER OF FORCE B.'
      READ*, BPB
      BPB = SB0 - ((BPB / 100) * SB0)

121   WRITE (7,130) 'INITIAL STRENGTH', SA0, FCA0, FPA0, SB0, FCB0, FPB0
     +,'FORCE STRENGTH AT EACH ITERATION'
130   FORMAT (1X,A16//5X,'SA',4X,'FCA',4X,'FPA',5X,'SB',4X,'FCB',4X,
     +'FPB'/42('_')//1X,6(F6.2,1X)//1X,A32//4X,'I',7X,'SA',6X,'FCA',6X,
     +'FPA',7X,'SB',6X,'FCB',6X,'FPB'/59('_')//)
```

```
      TOTPFP = 0
      PA     = 1
      JPA    = 1
      PB     = 1
      JPB    = 1
      CA     = 1
      JCA    = 1
      CB     = 1
      JCB    = 1
      HA     = 1
      HB     = 1
      SP     = 0
      L      = 0
      FC     = 0
      FCATOT = 0
      FCBTOT = 0
      FPATOT = 0
      FPBTOT = 0
      SATOT  = 0
      SBTOT  = 0

      DO 390 I = 1, N

140      IF (FIREPA(JPA).EQ.I) THEN
            PRINT*, 'FORCE A IS FIRING A PULSE.'
            PRINT*, 'HOW MANY INCREMENTS UNTIL IT REACHES ITS TARGET?'
            READ*, K
            PRINT*, 'HOW MANY GROUPS OF FORCE A ARE FIRING?'
            READ*, NFAP
            PRINT*, 'WHICH GROUPS ARE FIRING?'
            READ*, (SHTPA(H), H = 1, NFAP)
            PRINT*, 'WHICH PULSED WEAPON TYPE IS TO BE FIRED?'
            READ*, L1
            DO 145 H = 1, NFAP
               TOTPFP = TOTPFP + FPA(SHTPA(H), L1)
145         CONTINUE
            PRINT*, 'THESE GROUPS CAN FIRE ',TOTPFP,' UNITS.'
            PRINT*, 'HOW MANY UNITS ARE THEY GOING TO FIRE?'
            READ*, PULSEA(PA)
            PRINT*, 'WHAT IS THE WEAPON EFFECTIVENESS OF THIS PULSE?'
            READ*, PPA(PA)
            PRINT*, 'HOW MANY GROUPS OF FORCE B ARE BEING FIRED UPON?'
            READ*, NBPF (PA)
            PRINT*, 'WHICH GROUPS ARE BEING FIRED UPON?'
            READ*, (TGTPA(PA,H), H = 1, NBPF(PA))
            IMPA(PA) = I + K - 1
            TOTPFP = 0
            PA = PA + 1
            JPA = JPA + 1
            GOTO 140
         END IF

150      IF (FIREPB(JPB).EQ.I) THEN
            PRINT*, 'FORCE B IS FIRING A PULSE.'
            PRINT*, 'HOW MANY INCREMENTS UNTIL IT REACHES ITS TARGET?'
            READ*, K
            PRINT*, 'HOW MANY GROUPS OF FORCE B ARE FIRING?'
            READ*, NFBP
            PRINT*, 'WHICH GROUPS ARE FIRING?'
            READ*, (SHTPB(H), H = 1, NFBP)
            PRINT*, 'WHICH PULSED WEAPON TYPE IS TO BE FIRED?'
            READ*, L1
            DO 155 H = 1, NFBP
               TOTPFP = TOTPFP + FPB(SHTPB(H), L1)
```

```
155       CONTINUE
          PRINT*, 'THESE GROUPS CAN FIRE ',TOTPFP,' UNITS.'
          PRINT*, 'HOW MANY UNITS ARE THEY GOING TO FIRE?'
          READ*, PULSEB(PB)
          PRINT*, 'WHAT IS THE WEAPON EFFECTIVENESS OF THIS PULSE?'
          READ*, PPB(PB)
          PRINT*, 'HOW MANY GROUPS OF FORCE A ARE BEING FIRED UPON?'
          READ*, NAPF(PB)
          PRINT*, 'WHICH GROUPS ARE BEING FIRED UPON?'
          READ*, (TGTPB(PB,H), H = 1, NAPF(PB))
          IMPB(PB) = I + K - 1
          TOTPFP = 0
          PB = PB + 1
          JPB = JPB + 1
          GOTO 150
       END IF

160    IF (FIRECA(JCA).EQ.I) THEN
          PRINT*, 'FORCE A IS COMMENCING CONTINUOUS FIRE.'
          PRINT*, 'HOW MANY GROUPS ARE FIRING?'
          READ*, NFA(CA)
          PRINT*, 'WHICH GROUPS ARE FIRING?'
          READ*, (SHTCA(CA,H), H = 1, NFA(CA))
          PRINT*, 'HOW MANY GROUPS OF FORCE B ARE BEING FIRED UPON?'
          READ*, NBCF(CA)
          PRINT*, 'WHICH GROUPS ARE BEING FIRED UPON?'
          READ*, (TGTCA(CA,H), H = 1, NBCF(CA))
          STOPCA(CA) = I + (DURCA(JCA) - 1)
          CA = CA + 1
          JCA = JCA + 1
          GOTO 160
       END IF

170    IF (FIRECB(JCB).EQ.I) THEN
          PRINT*, 'FORCE B IS COMMENCING CONTINUOUS FIRE.'
          PRINT*, 'HOW MANY GROUPS ARE FIRING?'
          READ*, NFB(CB)
          PRINT*, 'WHICH GROUPS ARE FIRING?'
          READ*, (SHTCB(CB,H), H = 1, NFB(CB))
          PRINT*, 'HOW MANY GROUPS OF FORCE A ARE BEING FIRED UPON?'
          READ*, NACF(CB)
          PRINT*, 'WHICH GROUPS ARE BEING FIRED UPON?'
          READ*, (TGTCB(CB,H), H = 1, NACF(CB))
          STOPCB(CB) = I + (DURCB(JCB) - 1)
          CB = CB + 1
          JCB = JCB + 1
          GOTO 170
       END IF

       DO 180 H = 1, GA
          LCA(H) = 0
          LPA(H) = 0
180    CONTINUE
       DO 190 H = 1, GB
          LCB(H) = 0
          LPB(H) = 0
190    CONTINUE

200    IF (IMPA(HA).EQ.I) THEN
          DO 210 H = 1, NBPF(HA)
             SP = SP + SB(TGTPA(HA,H))
210       CONTINUE
          CALL PFIRE(L, SP, PPA(HA), PULSEA(HA))
          DO 220 H = 1, NBPF(HA)
             LPB(TGTPA(HA,H)) = LPB(TGTPA(HA,H)) + L
```

```
220         CONTINUE
            HA = HA + 1
            SP = 0
            L = 0
            GOTO 200
         END IF

230      IF (IMPB(HB).EQ.I) THEN
            DO 240 H = 1, NAPF(HB)
               SP = SP + SA(TGTPB(HB,H))
240         CONTINUE
            CALL PFIRE(L, SP, PPB(HB), PULSEB(HB))
            DO 250 H = 1, NAPF(HB)
               LPA(TGTPB(HB,H)) = LPA(TGTPB(HB,H)) + L
250         CONTINUE
            HB = HB + 1
            SP = 0
            L = 0
            GOTO 230
         END IF

         DO 290 H = 1, CA
            IF (STOPCA(H).GE.I) THEN
               DO 260 G = 1, NFA(H)
                  FC = FC + FCA(SHTCA(H,G)) * PCA(SHTCA(H,G))
260            CONTINUE
               DO 270 G = 1, NBCF(H)
                  SP = SP + SB(TGTCA(H,G))
270            CONTINUE
               CALL CFIRE(L, SP, FC)
               DO 280 G = 1, NBCF(H)
                  LCB(TGTCA(H,G)) = LCB(TGTCA(H,G)) + L
280            CONTINUE
               FC = 0
               SP = 0
               L = 0
            END IF
290      CONTINUE

         DO 330 H = 1, CB
            IF (STOPCB(H).GE.I) THEN
               DO 300 G = 1, NFB(H)
                  FC = FC + FCB(SHTCB(H,G)) * PCB(SHTCB(H,G))
300            CONTINUE
               DO 310 G = 1, NACF(H)
                  SP = SP + SA(TGTCB(H,G))
310            CONTINUE
               CALL CFIRE(L, SP, FC)
               DO 320 G = 1, NACF(H)
                  LCA(TGTCB(H,G)) = LCA(TGTCB(H,G)) + L
320            CONTINUE
               FC = 0
               SP = 0
               L = 0
            END IF
330      CONTINUE

         DO 350 H = 1, GA
            LA(H) = LCA(H) + LPA(H)
            IF (LA(H).GT.1) LA(H) = 1
            CALL TOTATT (LA(H), FCA(H), SA(H))
            DO 340, G = 1, NWA
               CALL PULATT(LA(H), FPA(H,G))
               FPATOT = FPATOT + FPA(H,G)
340         CONTINUE
```

```
         SATOT = SATOT + SA(H)
         FCATOT = FCATOT + FCA(H)
350   CONTINUE

      DO 370 H = 1, GB
         LB(H) = LCB(H) + LPB(H)
         IF (LB(H).GT.1) LB(H) = 1
         CALL TOTATT (LB(H), FCB(H), SB(H))
         DO 360, G = 1, NWB
            CALL PULATT(LB(H), FPB(H,G))
            FPBTOT = FPBTOT + FPB(H,G)
360      CONTINUE
         SBTOT = SBTOT + SB(H)
         FCBTOT = FCBTOT + FCB(H)
370   CONTINUE

      WRITE (7,380) I, SATOT, FCATOT, FPATOT, SBTOT, FCBTOT, FPBTOT
380   FORMAT (1X, I4, 6(2X, F7.3))

      IF ((SATOT.LE.BPA).OR.(SBTOT.LE.BPB)) GOTO 395
      IF (I.EQ.N) GOTO 395

      FCATOT = 0
      FCBTOT = 0
      FPATOT = 0
      FPBTOT = 0
      SATOT = 0
      SBTOT = 0

390   CONTINUE

395   TLSA = (1 - (SATOT/SA0)) * 100
      TLSB = (1 - (SBTOT/SB0)) * 100
      IF (FCA0.GT.0) THEN
         TLCA = (1 - (FCATOT/FCA0)) * 100
      ELSE
         TLCA = 0
      END IF
      IF (FCB0.GT.0) THEN
         TLCB = (1 - (FCBTOT/FCB0)) * 100
      ELSE
         TLCB = 0
      END IF
      IF (FPA0.GT.0) THEN
         TLPA = (1 - (FPATOT/FPA0)) * 100
      ELSE
         TLPA = 0
      END IF
      IF (FPB0.GT.0) THEN
         TLPB = (1 - (FPBTOT/FPB0)) * 100
      ELSE
         TLPB = 0
      END IF

      PRINT*

      WRITE (6,400) 'SUMMARY OF LOSSES (% LOST)',TLSA,TLCA,TLPA,TLSB,
     +TLCB,TLPB
      WRITE (7,400) 'SUMMARY OF LOSSES (% LOST)',TLSA,TLCA,TLPA,TLSB,
     +TLCB,TLPB
400   FORMAT (/1X,A26//5X,'SA',4X,'FCA',4X,'FPA',5X,'SB',4X,'FCB',4X,
     +'FPB'/1X,42('_')//1X,6(F6.2,1X))

      PRINT*
```

```
      END

      SUBROUTINE CFIRE(L, SP, FC)
      REAL L, SP, FC
      IF (SP.GT.0) THEN
          L = FC / SP
      ELSE
          L = 0
      END IF
      RETURN
      END

      SUBROUTINE PFIRE(L, SP, PP, PULSE)
      REAL L, SP, PP, PULSE
      IF (SP.GT.0) THEN
          L = (PULSE*PP)/SP
      ELSE
          L = 0
      END IF
      RETURN
      END

      SUBROUTINE TOTATT(L, FC, S)
      REAL L, FC, S
      FC = FC * (1 - L)
      S = S * (1 - L)
      RETURN
      END

      SUBROUTINE PULATT(L, FP)
      REAL L, FP
      FP = FP * (1 - L)
      RETURN
      END
^Z
```

B. SAMPLE OUTPUT FILE

This file listing is the program's output for the model run of the Battle of Coronel discussed in Chapter IV. At the top of the listing are printed the initial SP, FC, and FP values for forces A and B. The body of the listing includes the SP, FC and FP values of both forces at each time-step (I). At the bottom of the listing are the loss percentages for both forces at the end of the engagement.

INITIAL STRENGTH

SA	FCA	FPA	SB	FCB	FPB
4.44	7.69	0.00	5.53	8.65	0.00

FORCE STRENGTH AT EACH ITERATION

I	SA	FCA	FPA	SB	FCB	FPB
1	4.319	7.416	0.000	5.530	8.650	0.000
2	4.198	7.142	0.000	5.530	8.650	0.000
3	4.077	6.868	0.000	5.530	8.650	0.000
4	3.956	6.594	0.000	5.530	8.650	0.000
5	3.835	6.320	0.000	5.530	8.650	0.000
6	3.714	6.046	0.000	5.518	8.635	0.000
7	3.594	5.773	0.000	5.506	8.619	0.000
8	3.474	5.501	0.000	5.495	8.604	0.000
9	3.354	5.230	0.000	5.483	8.588	0.000
10	3.235	4.960	0.000	5.471	8.573	0.000
11	3.116	4.691	0.000	5.459	8.558	0.000
12	2.998	4.423	0.000	5.448	8.542	0.000
13	2.880	4.156	0.000	5.436	8.527	0.000
14	2.762	3.890	0.000	5.424	8.511	0.000
15	2.645	3.625	0.000	5.412	8.496	0.000
16	2.528	3.360	0.000	5.401	8.481	0.000
17	2.412	3.097	0.000	5.389	8.465	0.000
18	2.296	2.835	0.000	5.377	8.450	0.000
19	2.155	2.565	0.000	5.365	8.434	0.000
20	2.014	2.296	0.000	5.354	8.419	0.000
21	1.900	2.036	0.000	5.354	8.419	0.000
22	1.785	1.777	0.000	5.354	8.419	0.000
23	1.671	1.518	0.000	5.354	8.419	0.000
24	1.556	1.258	0.000	5.354	8.419	0.000
25	1.442	0.999	0.000	5.354	8.419	0.000
26	1.327	0.740	0.000	5.354	8.419	0.000
27	1.213	0.480	0.000	5.354	8.419	0.000
28	1.178	0.402	0.000	5.354	8.419	0.000
29	1.178	0.402	0.000	5.354	8.419	0.000
30	1.178	0.402	0.000	5.354	8.419	0.000

SUMMARY OF LOSSES (% LOST)

SA	FCA	FPA	SB	FCB	FPB
73.47	94.77	0.00	3.19	2.67	0.00

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